US011406817B2

(12) **United States Patent**
Stevenson et al.

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(45) **Date of Patent:** **Aug. 9, 2022**

(54) **LOW EQUIVALENT SERIES RESISTANCE RF FILTER CIRCUIT BOARD FOR AN ACTIVE IMPLANTABLE MEDICAL DEVICE**

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(73) Assignee: **Greatbatch Ltd.**, Clarence, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 177 days.

(21) Appl. No.: **16/880,392**

(22) Filed: **May 21, 2020**

(65) **Prior Publication Data**

US 2020/0276440 A1 Sep. 3, 2020

Related U.S. Application Data

(63) Continuation-in-part of application No. 16/827,171, filed on Mar. 23, 2020, now Pat. No. 11,071,858, (Continued)

(51) **Int. Cl.**
A61N 1/08	(2006.01)
H01G 4/005	(2006.01)
H01G 4/30	(2006.01)
H01G 4/35	(2006.01)
H01G 4/236	(2006.01)
(Continued)

(52) **U.S. Cl.**
CPC *A61N 1/08* (2013.01); *A61N 1/3754* (2013.01); *A61N 1/3758* (2013.01); *H01G 4/005* (2013.01); *H01G 4/236* (2013.01); *H01G 4/30* (2013.01); *H01G 4/35* (2013.01);

A61N 1/086 (2017.08); *A61N 1/375* (2013.01); *A61N 1/3718* (2013.01); *H01G 4/12* (2013.01); *H03H 1/0007* (2013.01)

(58) **Field of Classification Search**
CPC A61N 1/08; A61N 1/3754; A61N 1/3758; A61N 1/086; A61N 1/3718; A61N 1/375; H01G 4/005; H01G 4/236; H01G 4/30; H01G 4/35; H01G 4/12; H03H 1/0007
USPC 607/36
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2009/0243756 A1* 10/2009 Stevenson A61N 1/3754
                                                      333/172
2012/0016444 A1* 1/2012 Koester A61N 1/3754
                                                      607/57

* cited by examiner

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(74) *Attorney, Agent, or Firm* — Michael F. Scalise

(57) **ABSTRACT**

A filtered feedthrough assembly includes a ferrule configured to be installed in an AIMD housing. An insulator is disposed within a ferrule opening. A conductive pathway is disposed within a passageway through the insulator. A filter capacitor is disposed on a device side having active and ground electrode plates disposed within a capacitor dielectric k greater than 0 and less than 1,000. A capacitor active metallization is electrically connected to the active electrode plates. A ground capacitor metallization is electrically connected to the ground electrode plates. The filter capacitor is the first filter capacitor electrically connected to the conductive pathway coming from a body fluid side into the device side. An active electrical connection electrically connects the conductive pathway to the capacitor active metallization. A ground electrical connection electrically connects the ground capacitor metallization to the ferrule. The filter capacitor is a flat-through or an X2Y attenuator filter capacitor.

21 Claims, 91 Drawing Sheets
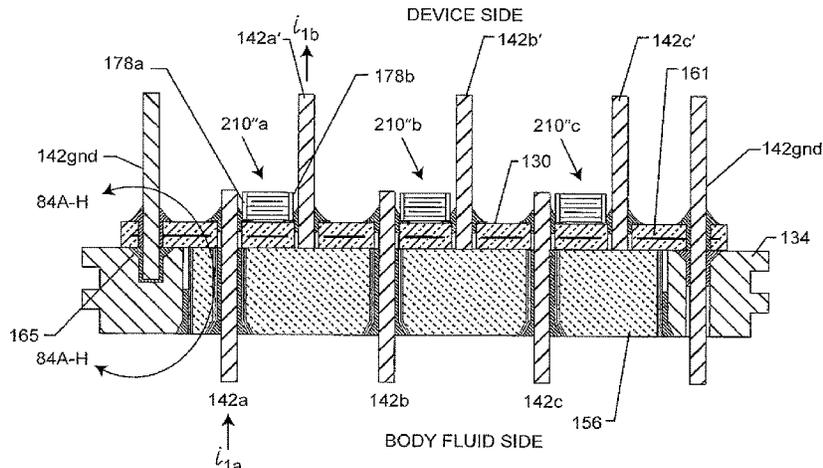
Related U.S. Application Data

which is a continuation of application No. 16/121,716, filed on Sep. 5, 2018, now Pat. No. 10,596,369, which is a continuation-in-part of application No. 15/943,998, filed on Apr. 3, 2018, now Pat. No. 10,350,421, application No. 16/880,392, which is a continuation-in-part of application No. 15/797,278, filed on Oct. 30, 2017, now Pat. No. 10,272,253, which is a continuation-in-part of application No. 15/704,657, filed on Sep. 14, 2017, now Pat. No. 10,092,749, application No. 16/880,392, which is a continuation-in-part of application No. 15/603,521, filed on May 24, 2017, now Pat. No. 10,272,252, application No. 16/880,392, which is a continuation-in-part of application No. 15/250,210, filed on Aug. 29, 2016, now Pat. No. 9,931,514, which is a continuation-in-part of application No. 15/163,241, filed on May 24, 2016, now Pat. No. 9,764,129, which is a continuation-in-part of application No. 14/826,229, filed on Aug. 14, 2015, now Pat. No. 9,427,596, which is a continuation-in-part of application No. 14/688,302, filed on Apr. 16, 2015, now Pat. No. 9,757,558, which is a continuation-in-part of application No. 14/202,653, filed on Mar. 10, 2014, now Pat. No. 9,108,066, which is a continuation-in-part of application No. 13/873,832, filed on Apr. 30, 2013, now Pat. No. 8,868,189, application No. 16/880,392, which is a continuation-in-part of application No. 13/408,020, filed on Feb. 29, 2012, now abandoned, application No. 16/880,392, which is a continuation-in-part of application No. 16/589,752, filed on Oct. 1, 2019, which is a continuation of application No. 16/004,569, filed on Jun. 11, 2018, now Pat. No. 11,198,014.

(60) Provisional application No. 62/646,552, filed on Mar. 22, 2018, provisional application No. 62/552,363, filed on Aug. 30, 2017, provisional application No. 62/461,872, filed on Feb. 22, 2017, provisional application No. 62/450,187, filed on Jan. 25, 2017, provisional application No. 62/443,011, filed on Jan. 6, 2017, provisional application No. 62/422,064, filed on Nov. 15, 2016, provisional application No. 62/420,164, filed on Nov. 10, 2016, provisional application No. 61/841,419, filed on Jun. 30, 2013, provisional application No. 61/448,069, filed on Mar. 1, 2011, provisional application No. 61/448,069, filed on Mar. 1, 2011, provisional application No. 62/979,600, filed on Feb. 21, 2020.

(51) **Int. Cl.**

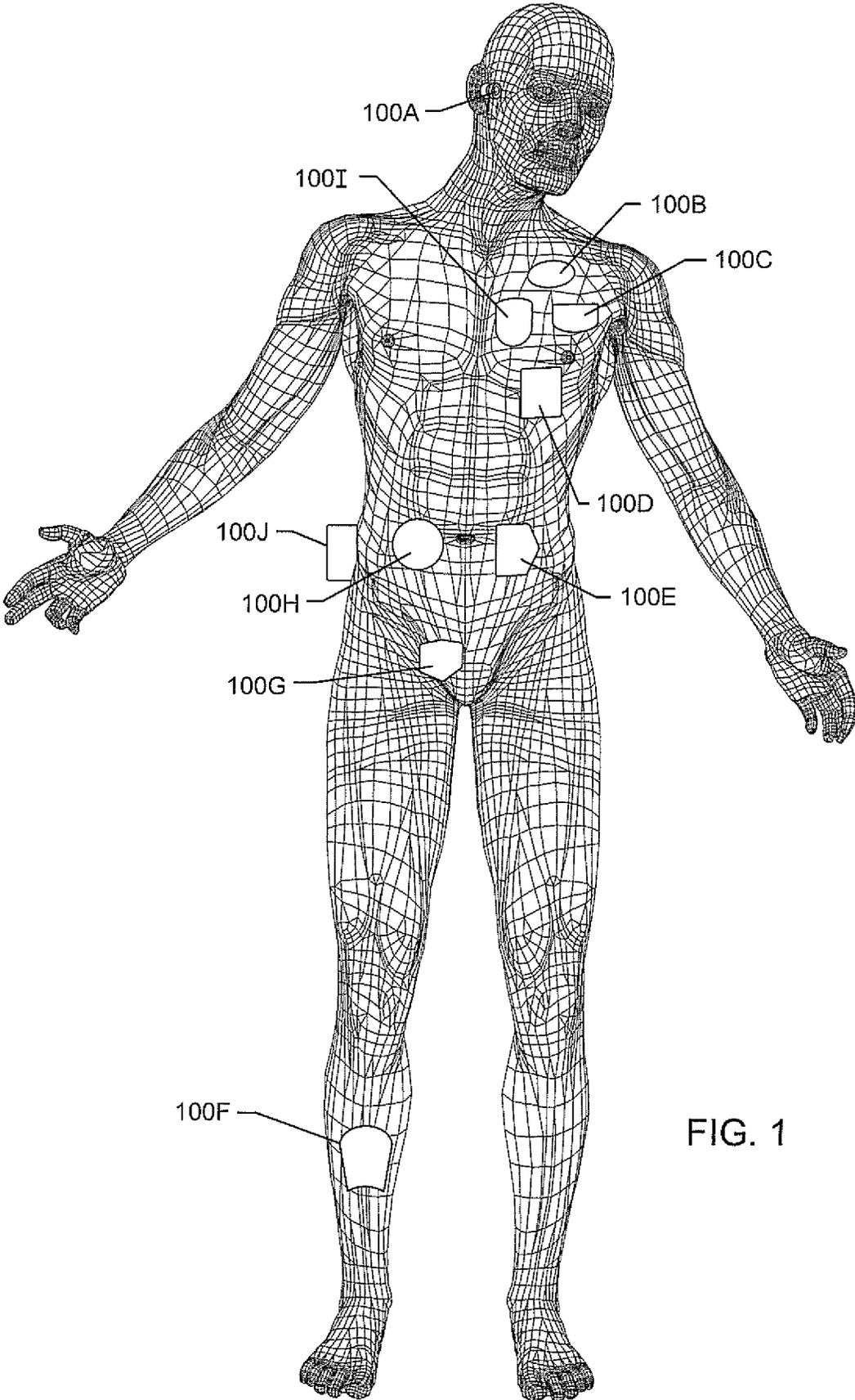|		
A61N 1/375	(2006.01)	
H01G 4/12	(2006.01)	
H03H 1/00	(2006.01)	
A61N 1/37	(2006.01)	

FIG. 1

FIG. 2
PRIOR ART
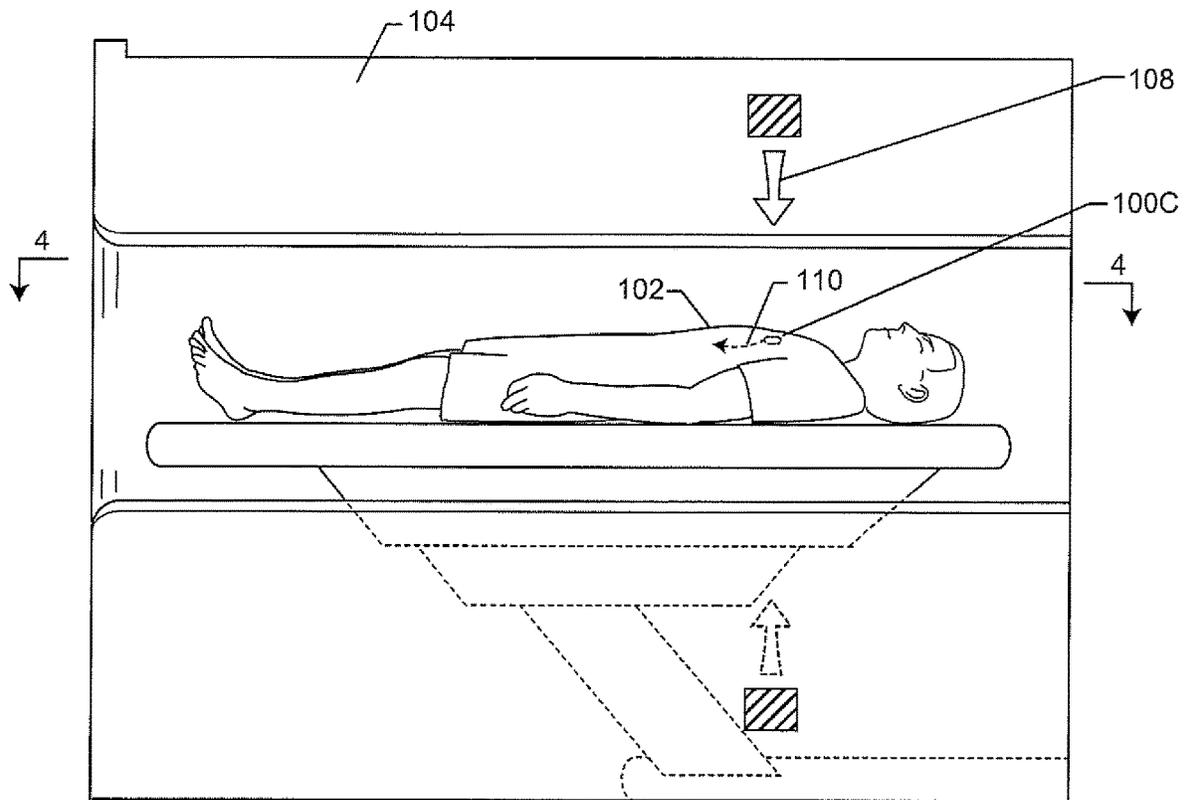
FIG. 3
PRIOR ART

FIG. 4
PRIOR ART

FIG. 5

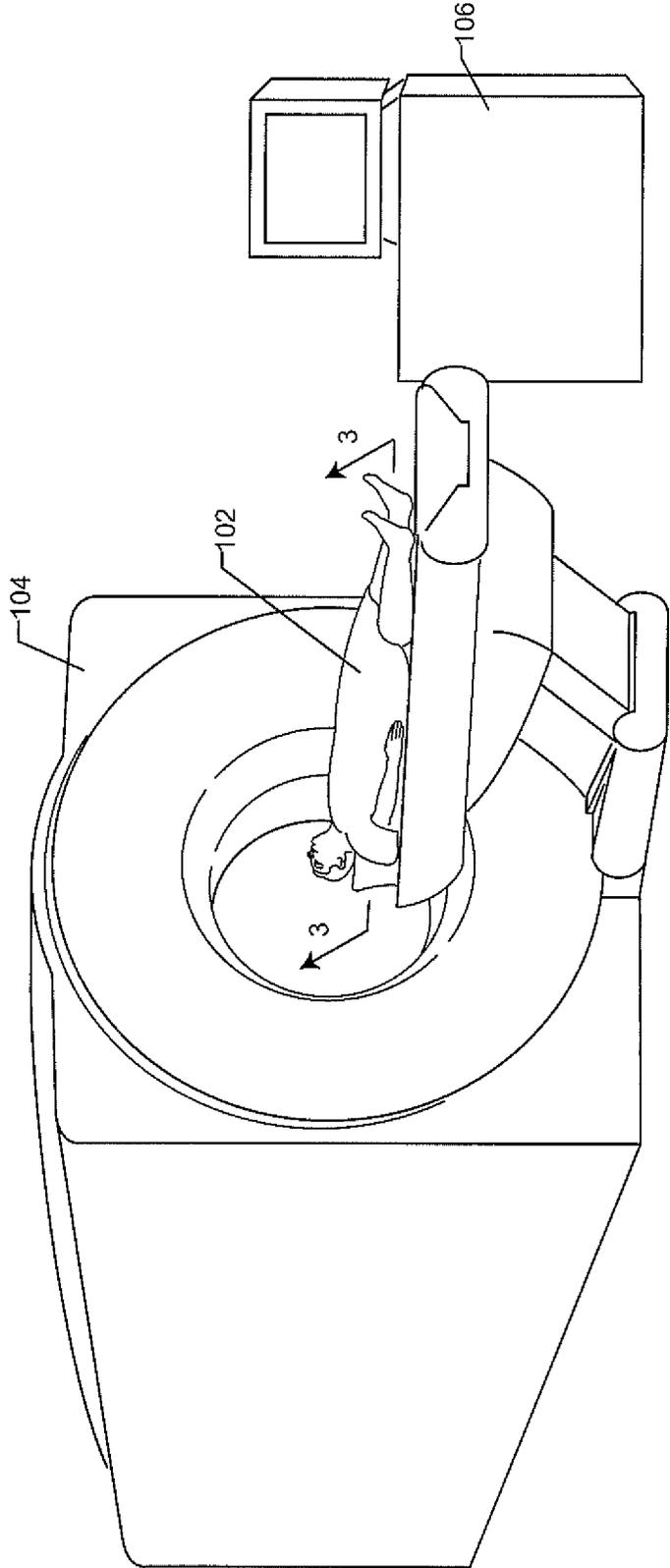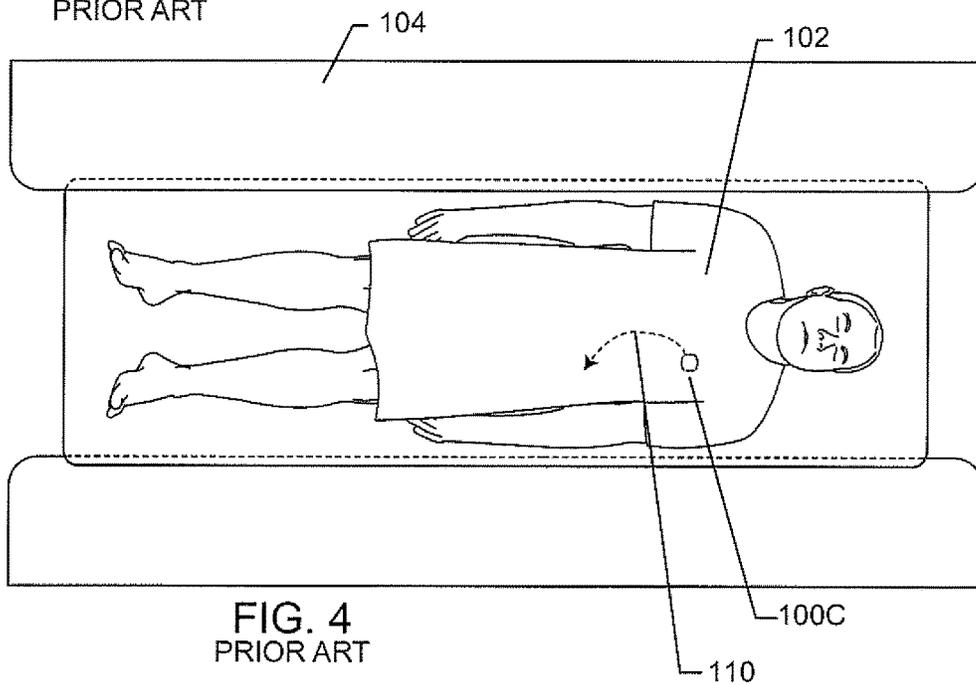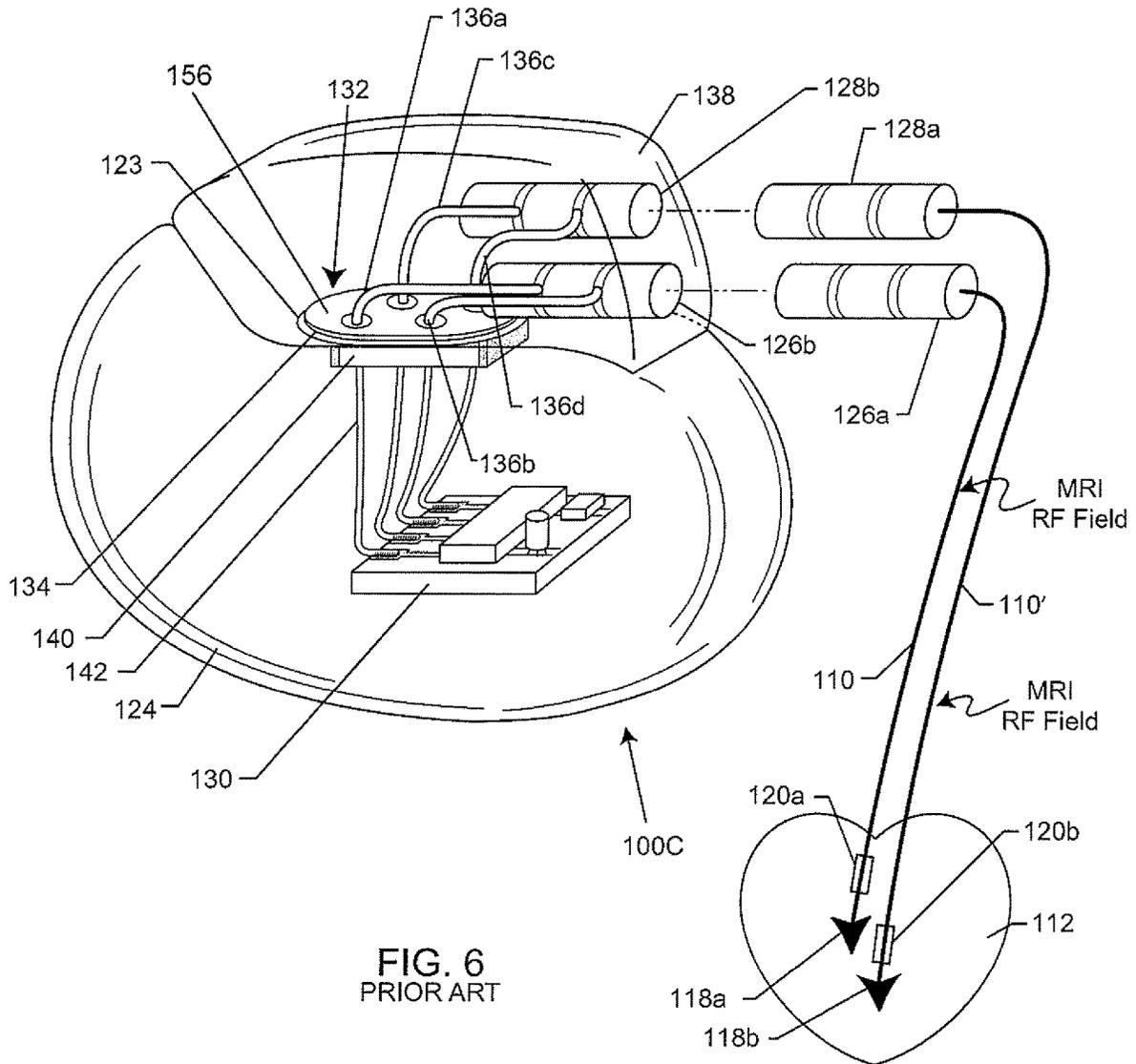FIG. 6
PRIOR ART

FIG. 7
PRIOR ART

BODY
FLUID
SIDE

FIG. 8
PRIOR ART

BODY
FLUID
SIDE

142

140

10

132

10

152

134

158

136

FIG. 9
PRIOR ART

BODY
FLUID
SIDE

148
166
140
150
142
144
168
146
164
172
170
152
132
124
157
134
136
156
154a
129
133
162
154b
136

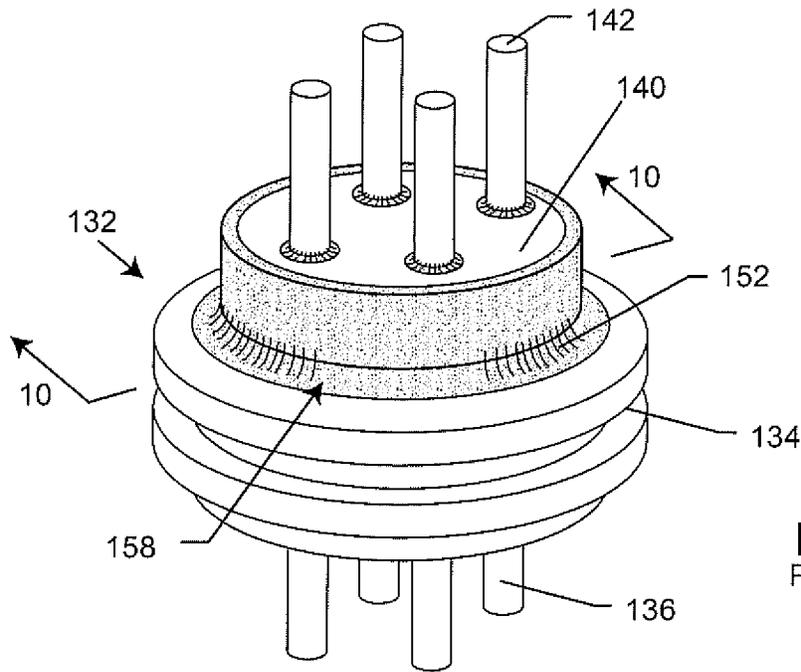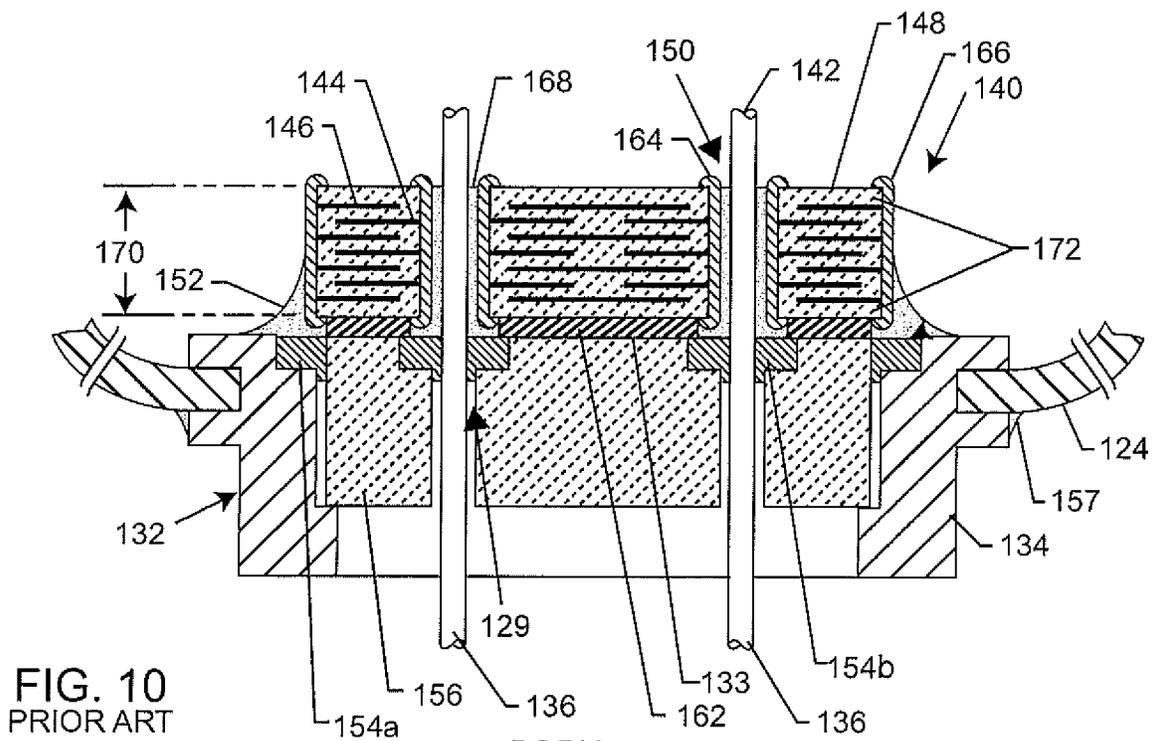**FIG. 10**
PRIOR ART

BODY
FLUID
SIDE

FIG. 11

BODY
FLUID
SIDE

FIG. 12

DEVICE SIDE
(INBOARD SIDE)

BODY
FLUID
SIDE

FIG. 13

DEVICE SIDE
(INBOARD SIDE)

140'

164

166

15

15

174

176

148'

FIG. 14
PRIOR ART

140'

144   146

174

166

164

176

148'

FIG. 15
PRIOR ART

140'

164,174   166,176
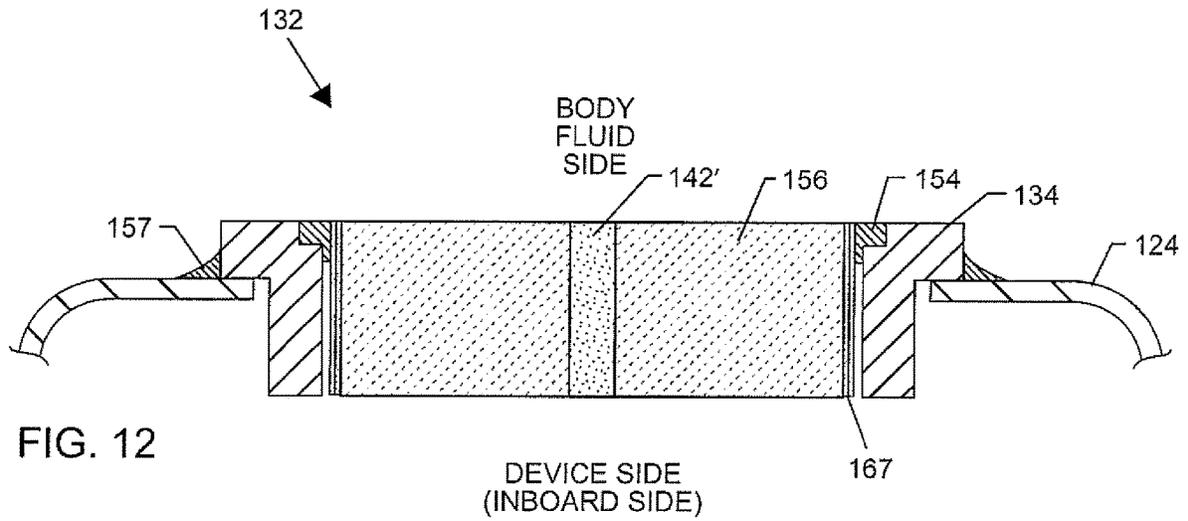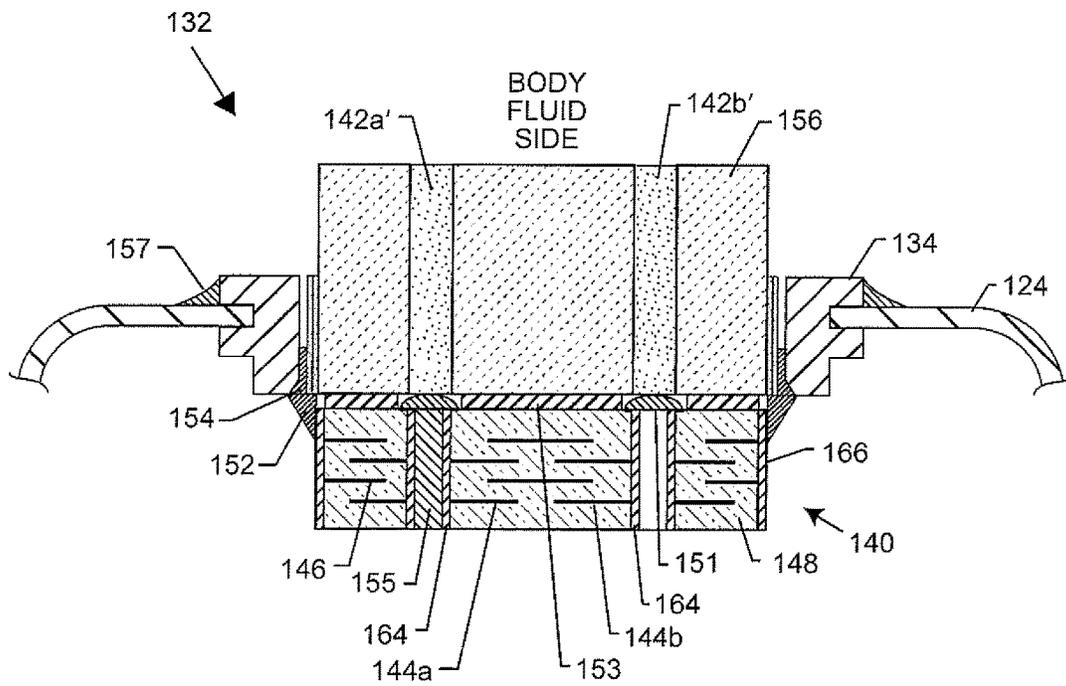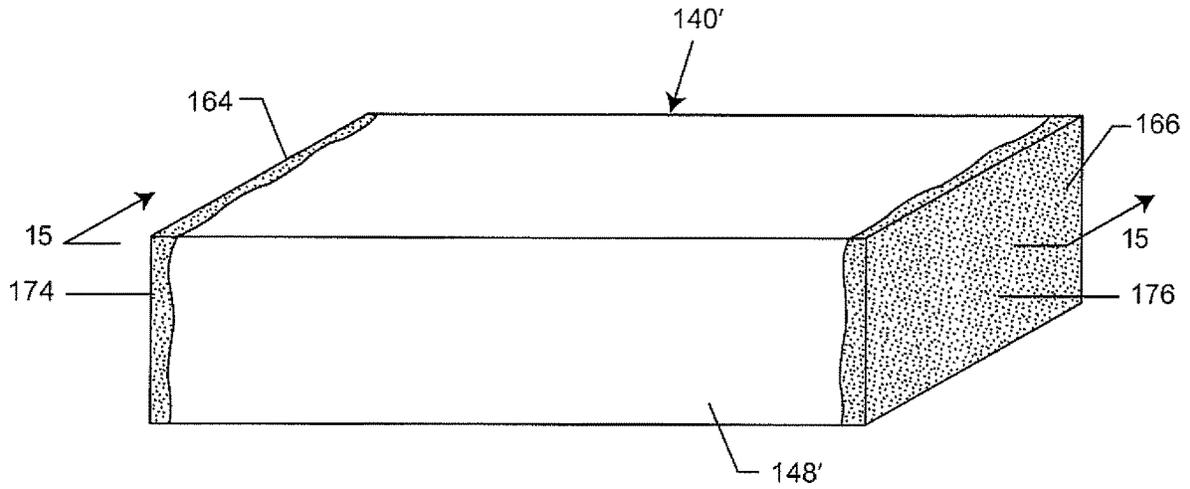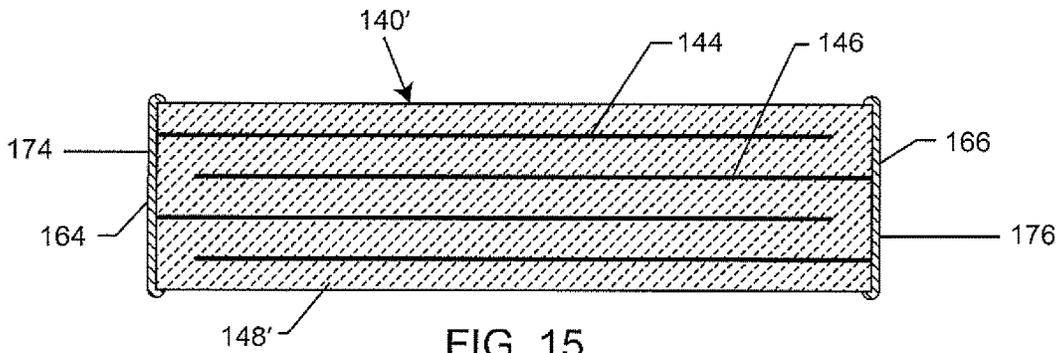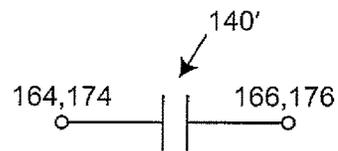
FIG. 16
PRIOR ART
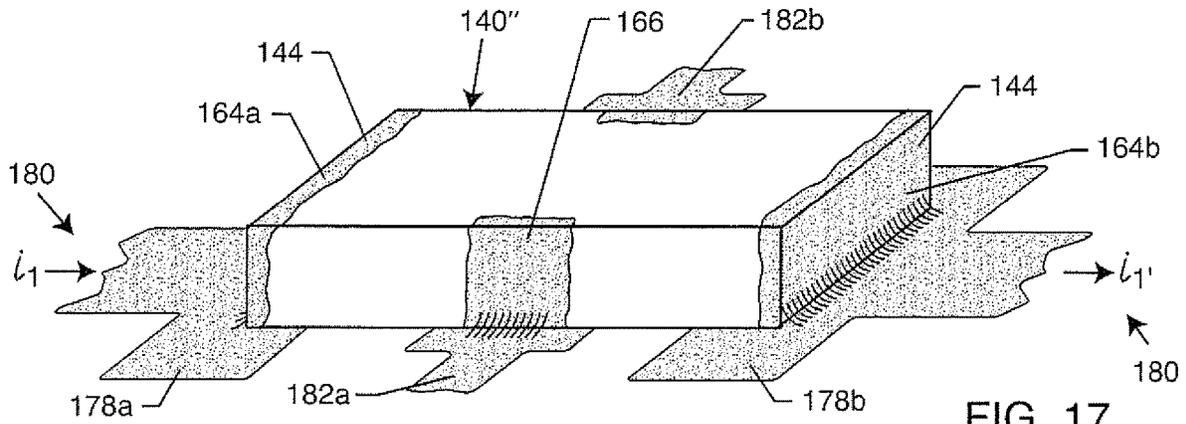
FIG. 17
PRIOR ART
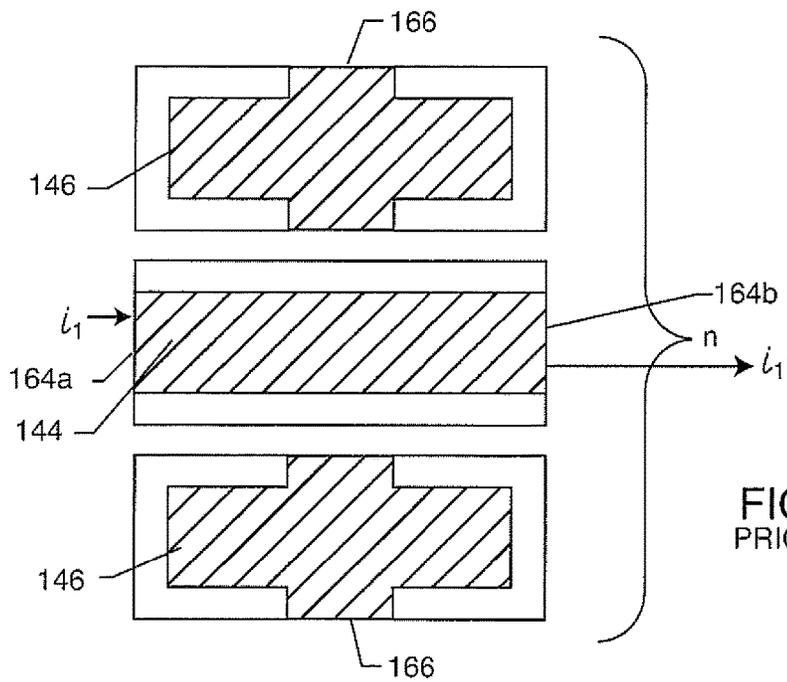
FIG. 18
PRIOR ART
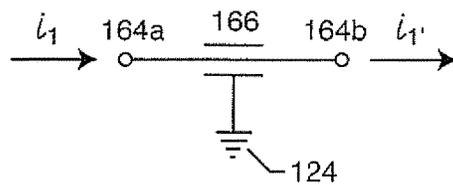
FIG. 18A

FIG. 19
PRIOR ART

FIG. 19A

(INSULATOR AND HERMETIC
SEAL NOT SHOWN)
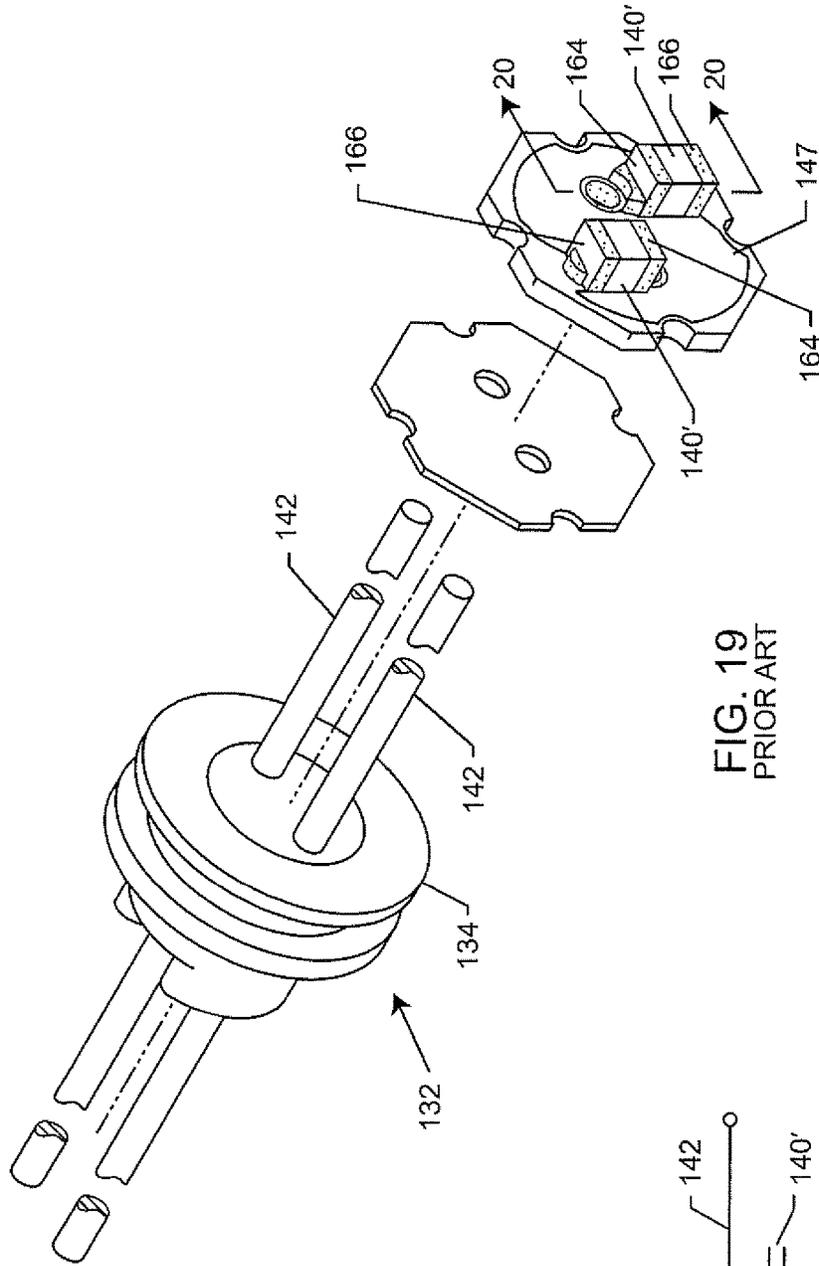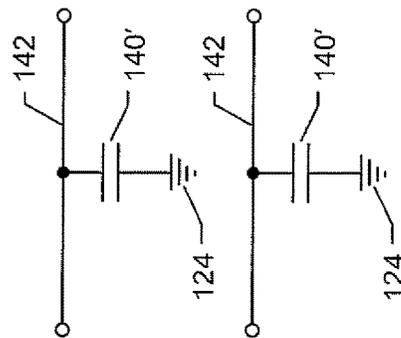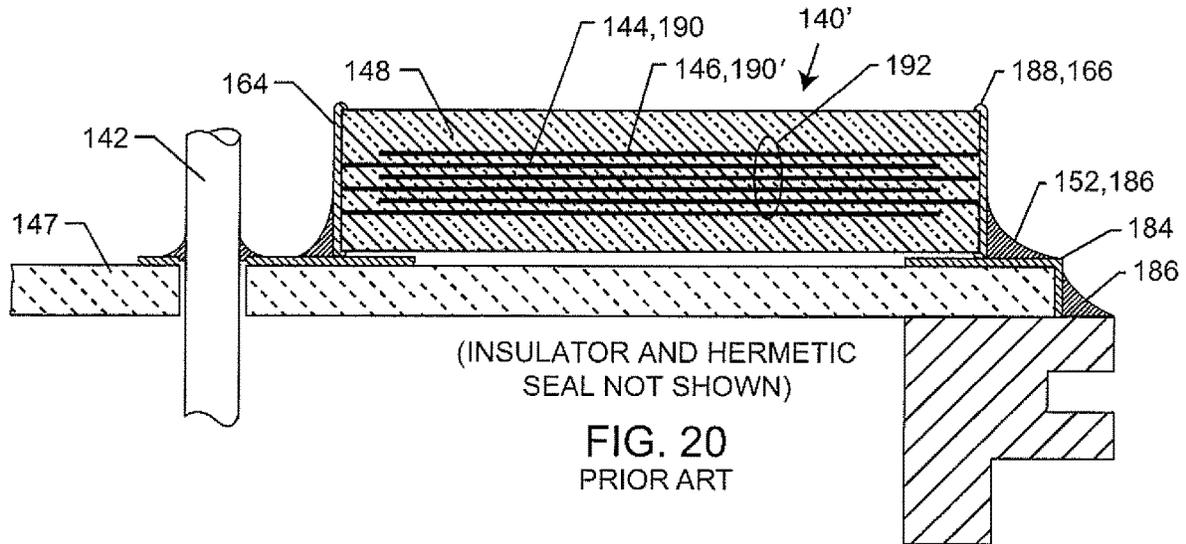
FIG. 20
PRIOR ART
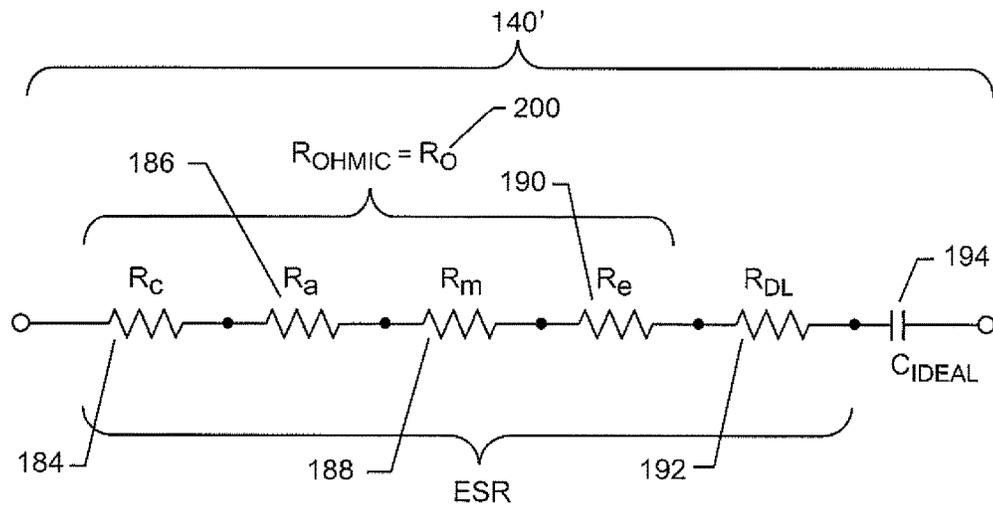
FIG. 21

$$C = \frac{kA\,(n-1)}{d}$$

Where

A = Active Area
C = Capacitance
k = Dielectric Constant
n = Number of Electrode Plates
d = Dielectric Thickness

FIG. 22
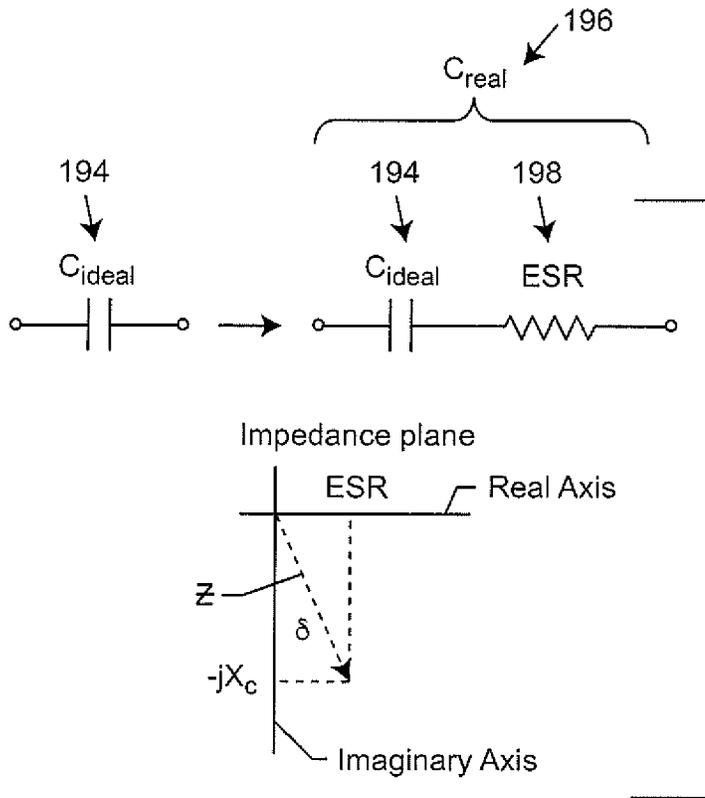
FIG. 23

$$X_c = -j \left(\frac{1}{\omega C} \right)$$

$$Z = \sqrt{X_c^2 + (ESR)^2}$$

$$DF = \frac{i^2 ESR}{i^2 |X_c|} = (\omega C) \cdot (ESR) = 1 / Q$$

$$\tan\delta = \frac{ESR}{|X_c|} = DF .$$

FIG. 24

140'

198

$ESR = R_{DL} + R_o$

R_{IR} — 202

C_{IDEAL}

R_{DL} R_o R_C ESL — 204

192   200   194   184
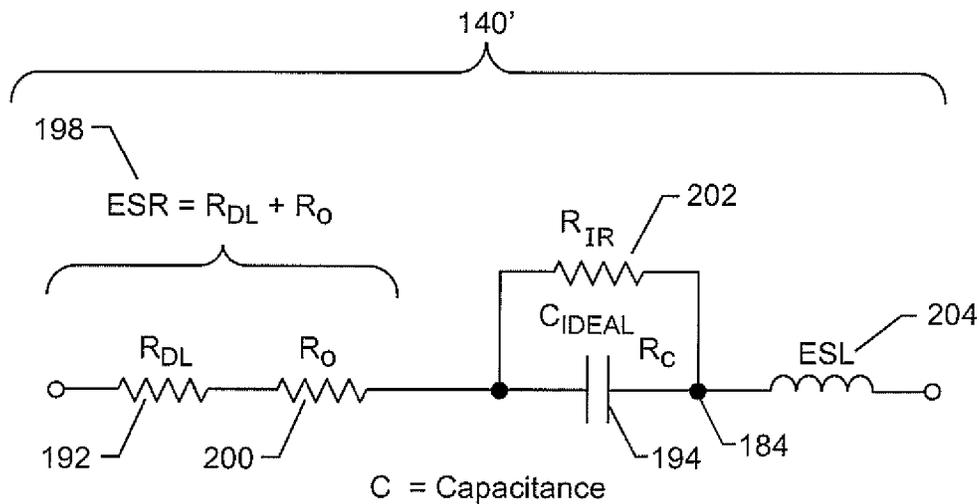
C = Capacitance

R_{DL} = R dielectric

FIG. 25

R_o = R ohmic loss

IR = Insulation Resistance

ESL = Equivalent Series Inductance

ESR = Equivalent Series Resistance

140'

192   200   194

R_{DL} R_o C_{IDEAL}

$ESR = R_{DL} + R_e = R_{DL} + R_o$ (Where $R_e \approx R_o$)

198   192   190   192   200
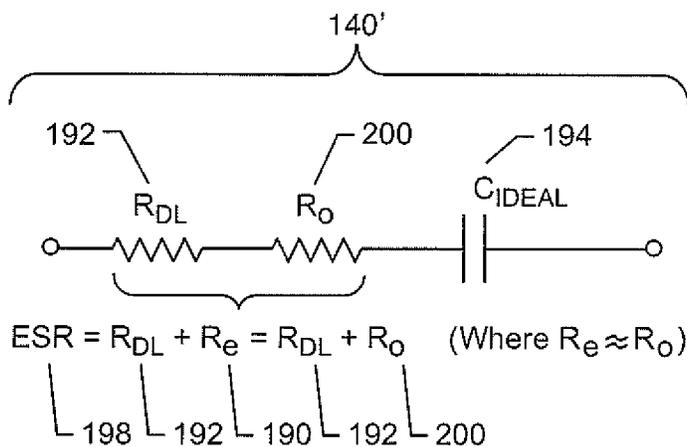
FIG. 26
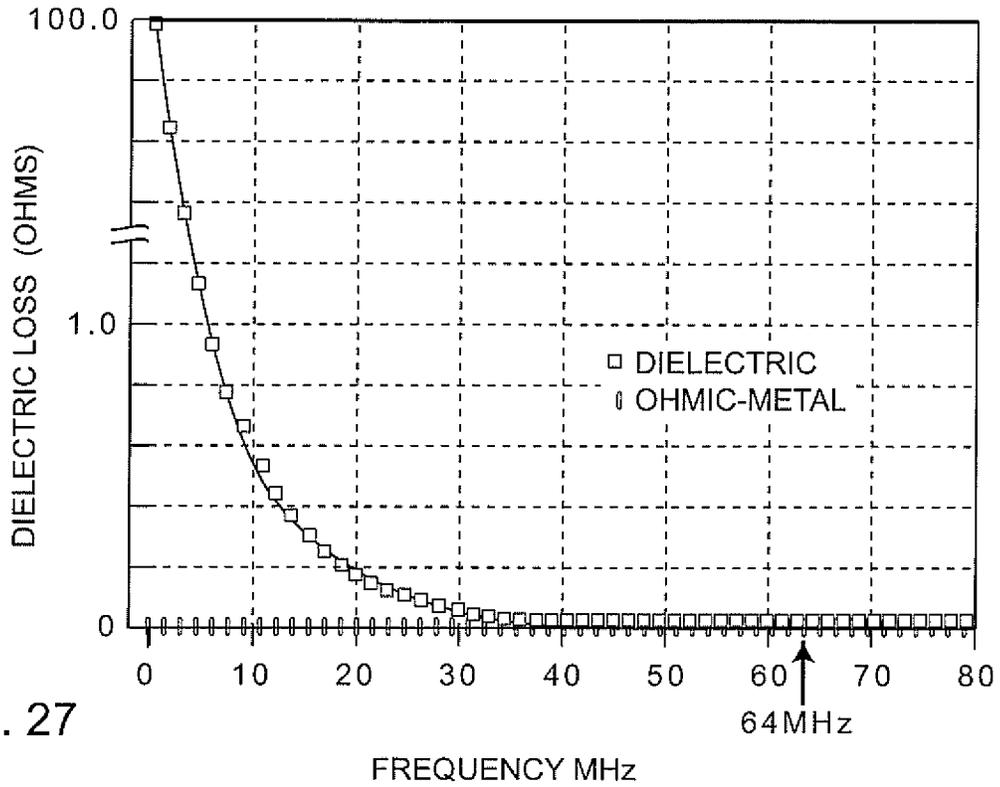
FIG. 27
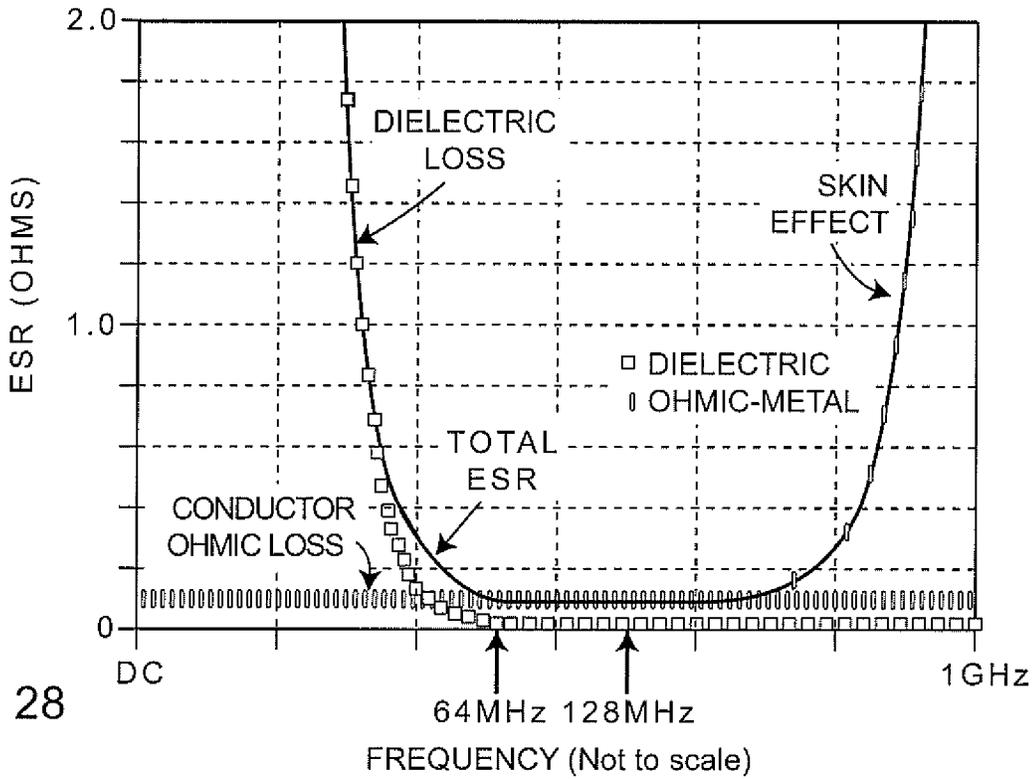
FIG. 28

Example of Losses in a 2000 P.F. X7R Capacitor

DF is a percentage of Xc ≈ dielectric loss tangent

Example: 2% DF Dielectric; 2000 picofarad FT (2.5% MAX Per EIA RS-198C)

Frequency	Xc (Ω)	DF (Ω)	R (Ω)	ESR = DF+R (Ω)
1 kHz	79,599.54	1591.55	0.432	1591.98
1 MHz	79.58	1.59	0.432	2.02
10 MHz	7.96	0.159	0.432	0.59
100 MHz	0.796	0.016	0.432	0.45
500 MHz	0.159	0.003	0.432	0.44

FIG. 29

Example of Losses in a 2000 P.F. COG (NPO) Capacitor

DF is a percentage of Xc

Example: 0.15% DF Dielectric; 2000 picofarad FT

Frequency	Xc (Ω)	DF (Ω)	R (Ω)	ESR = DF+R (Ω)
1 kHz	79,577.54	119.40	0.2	119.6
1 MHz	79.58	0.12	0.2	0.32
10 MHz	7.96	0.012	0.2	0.212
100 MHz	0.796	0.001	0.2	0.201
500 MHz	0.159	0.0	0.2	0.200

FIG. 30

FIG. 31

210

212 — 190 — 190' — 214

164 — — 166

142 — 152

147 —

(INSULATOR AND HERMETIC
SEAL NOT SHOWN)

124

157
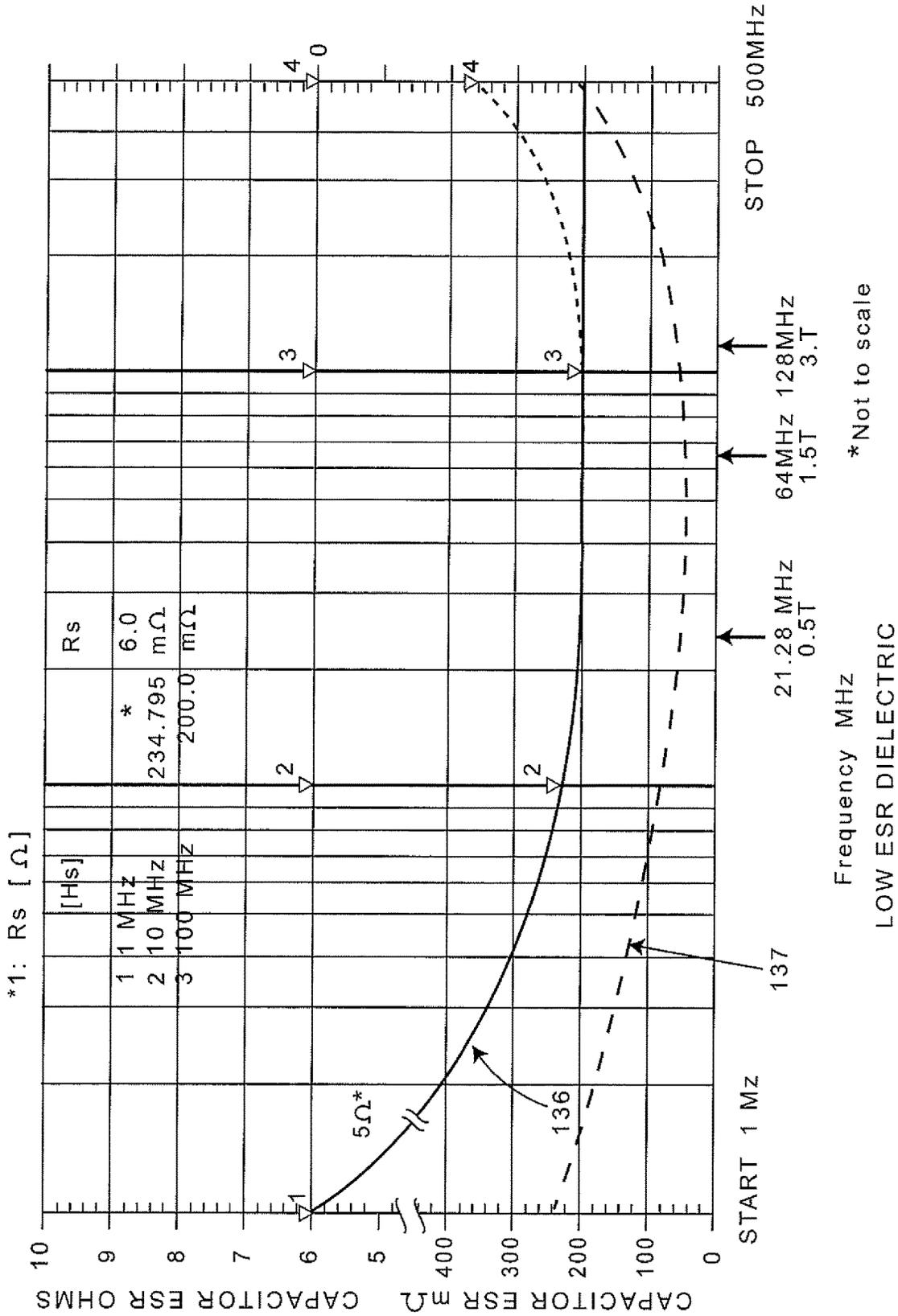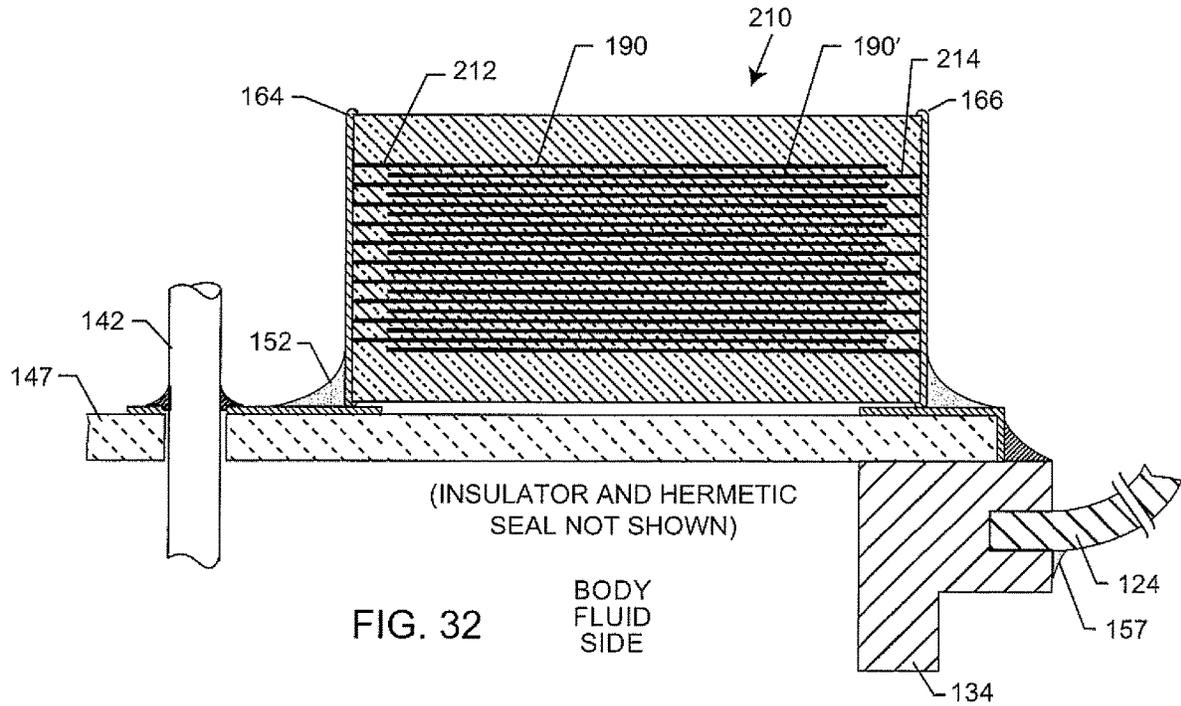
FIG. 32   BODY
FLUID
SIDE

134

$$R_{et} = \cfrac{1}{\cfrac{1}{R_{e_1}} + \cfrac{1}{R_{e_2}} + \cdots \cfrac{1}{R_{e_n}}}$$

FIG. 33
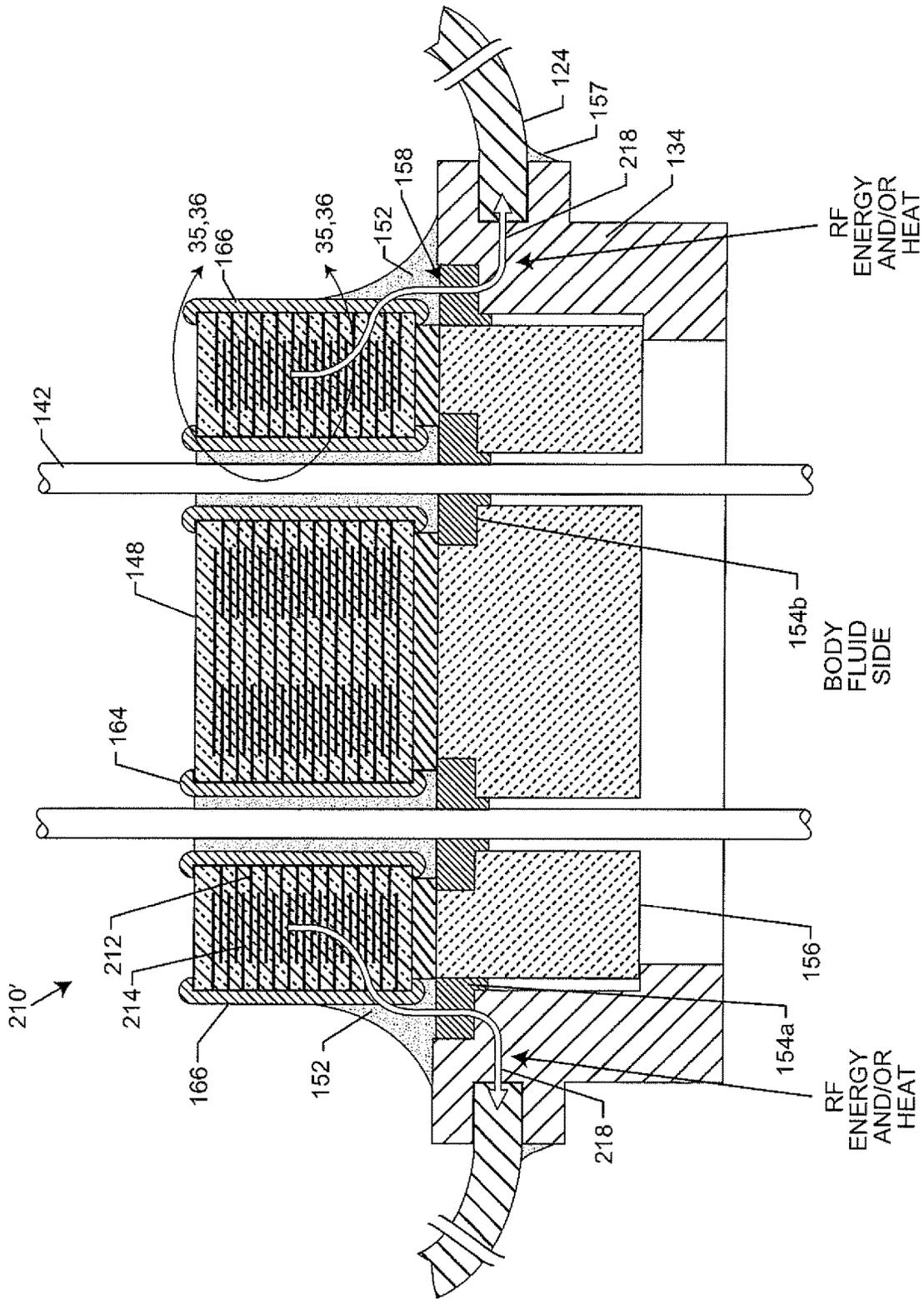
FIG. 34
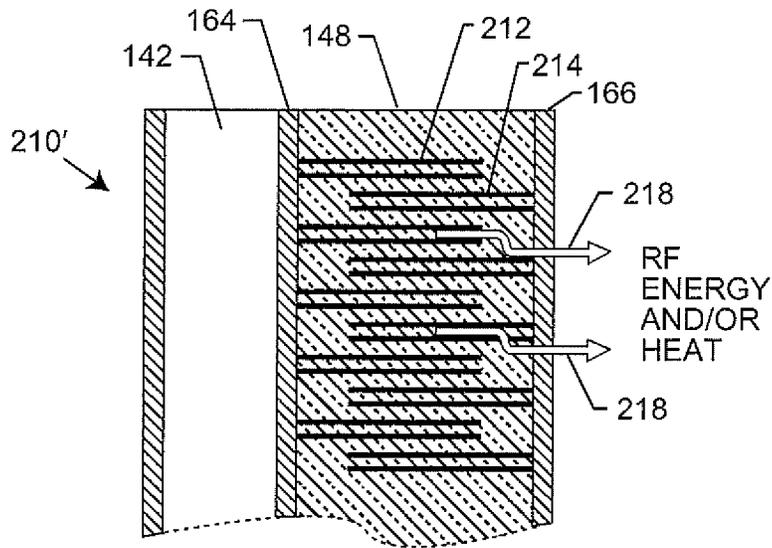
FIG. 35
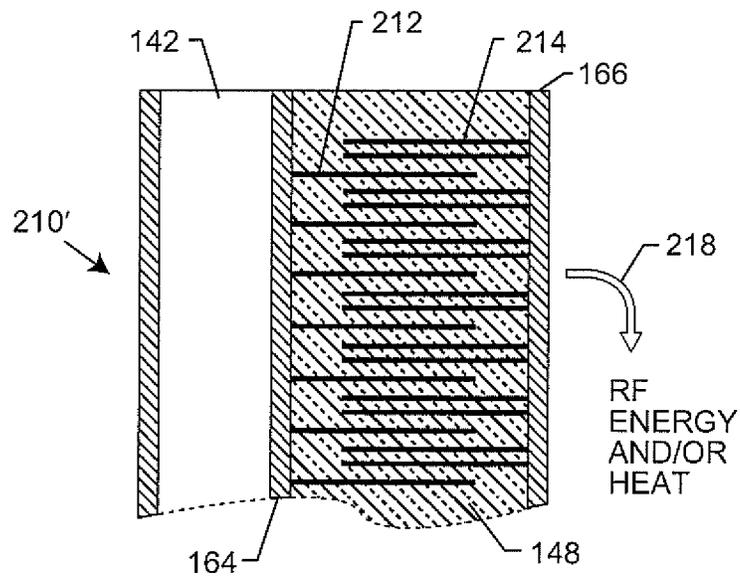
FIG. 36
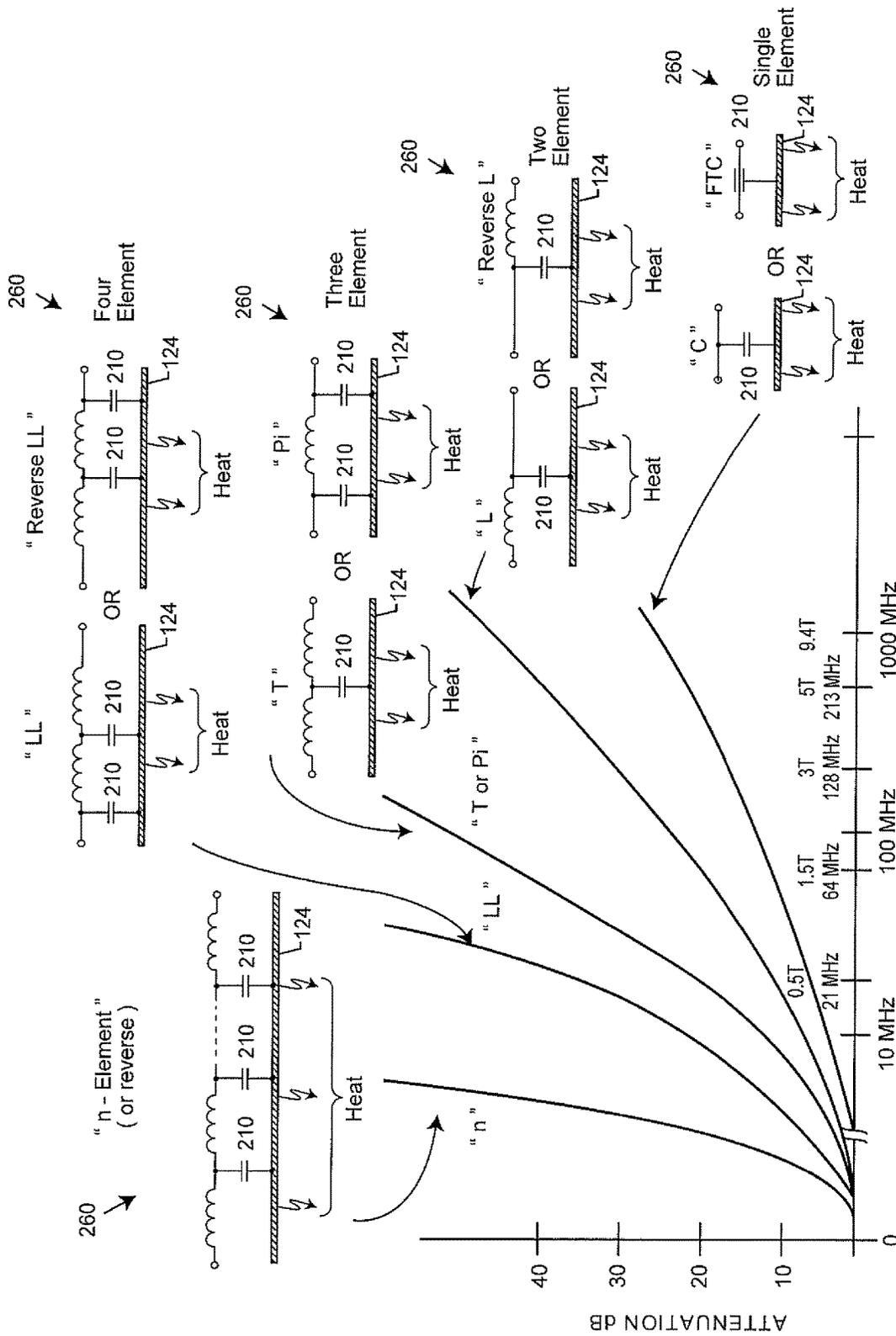
FIG. 37

FIG. 38

FIG. 39

FIG. 39A

136

156

134

124

182

210

142

152

171

143

152

TO
AIMD
CIRCUITS

FIG. 39B

136

142

210

134

124

RF/HEAT

FIG. 39C

FIG. 40

FIG.41

FIG. 42

FIG. 43

FIG. 44

FIG. 45

210"

FIG. 46

212   212   212   212   210"

FIG. 47

210"

214
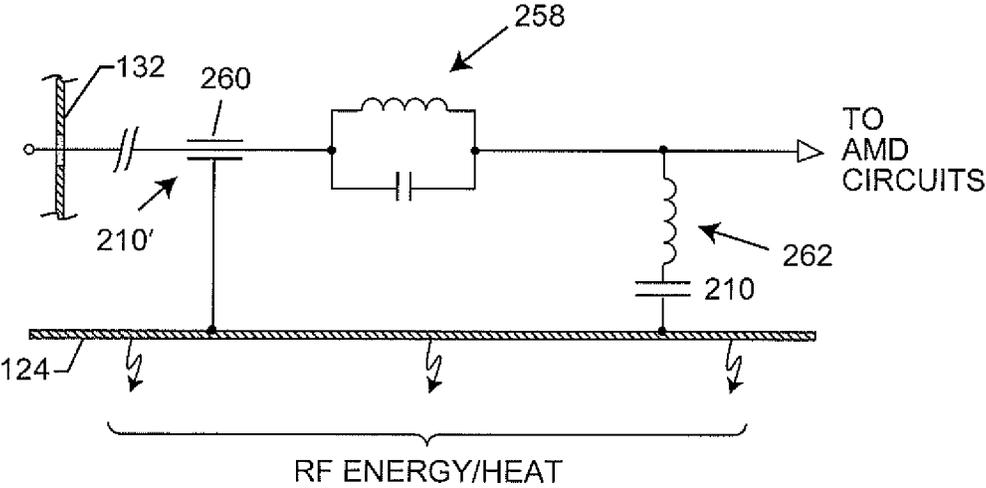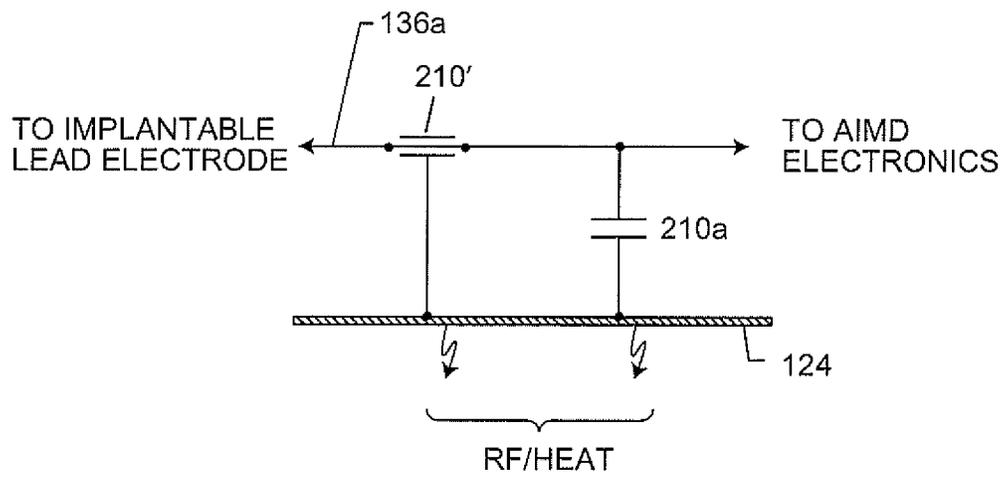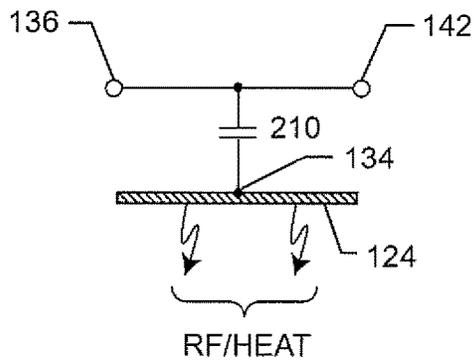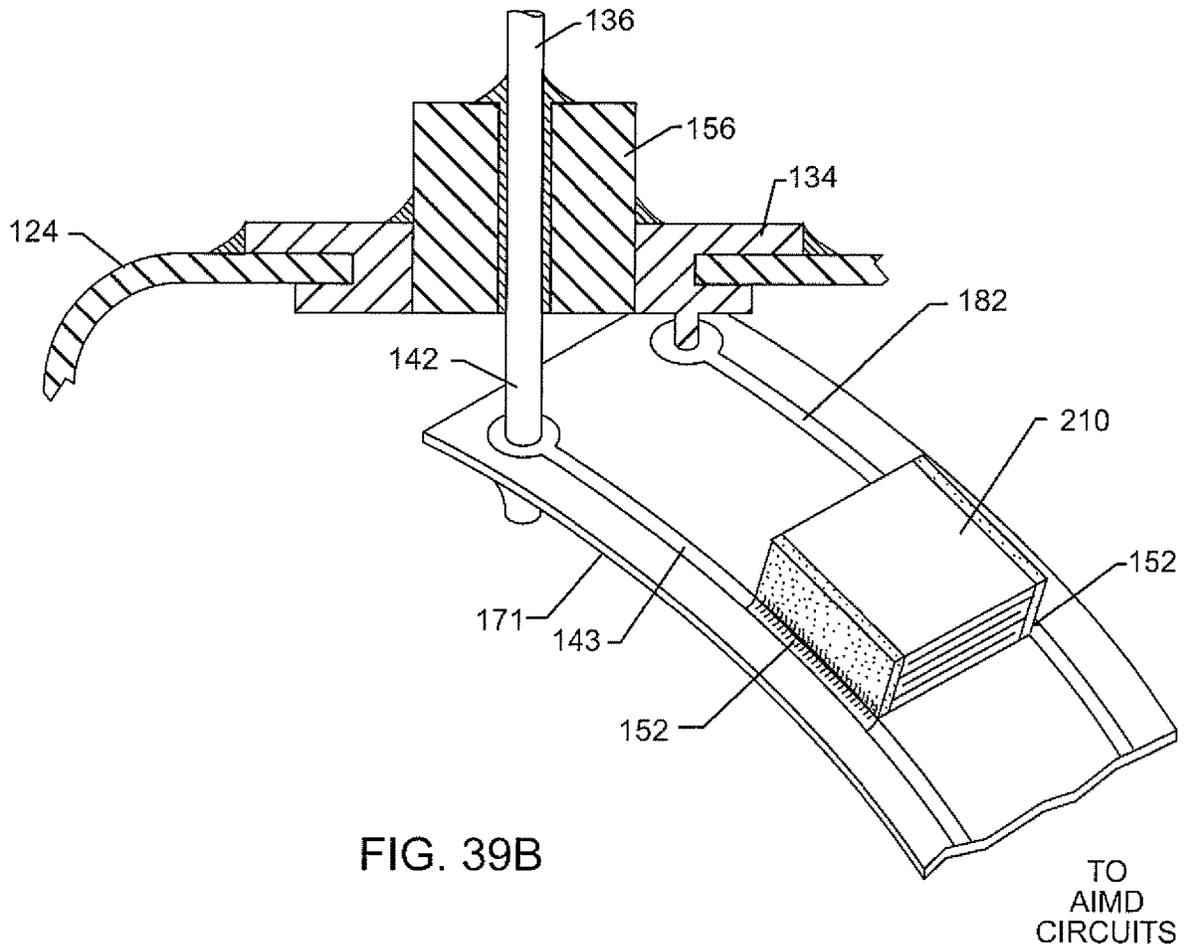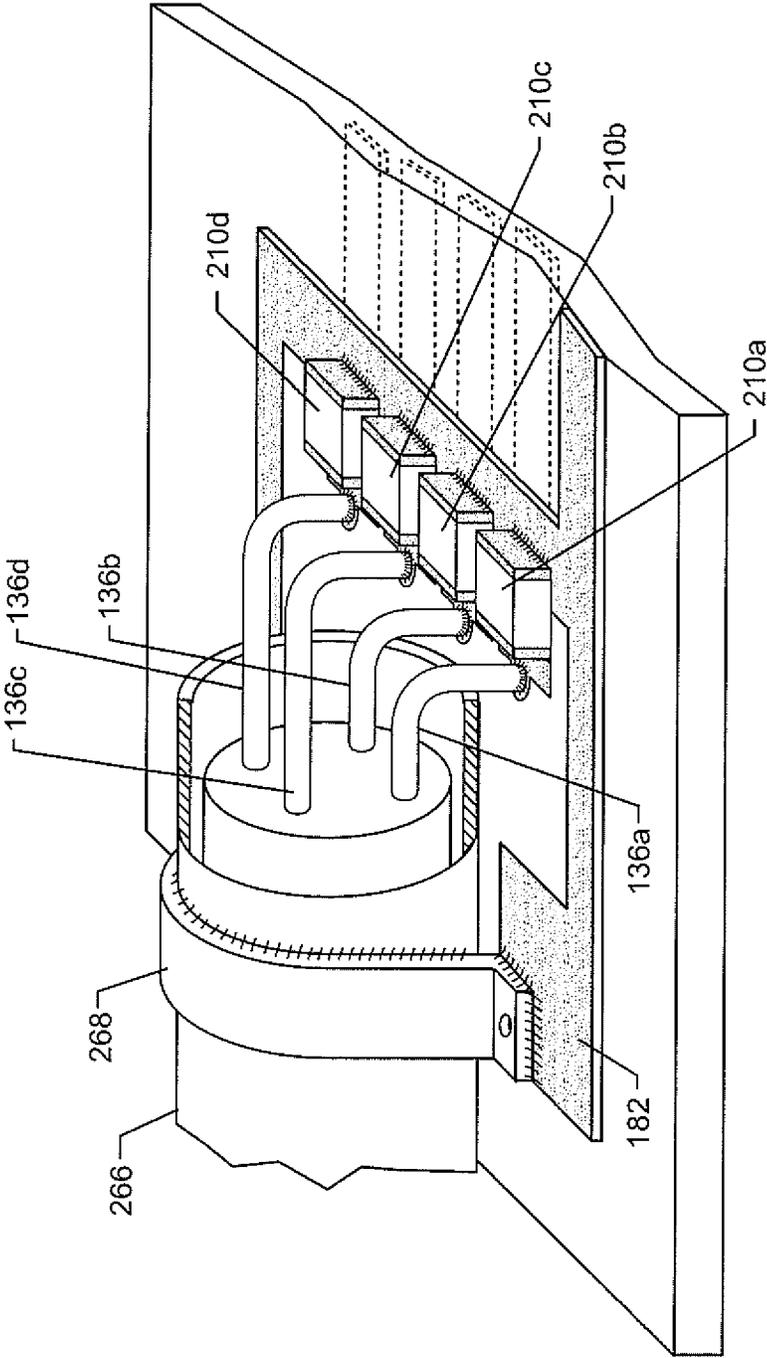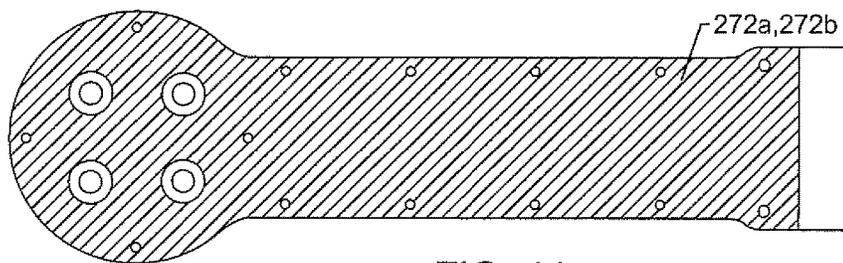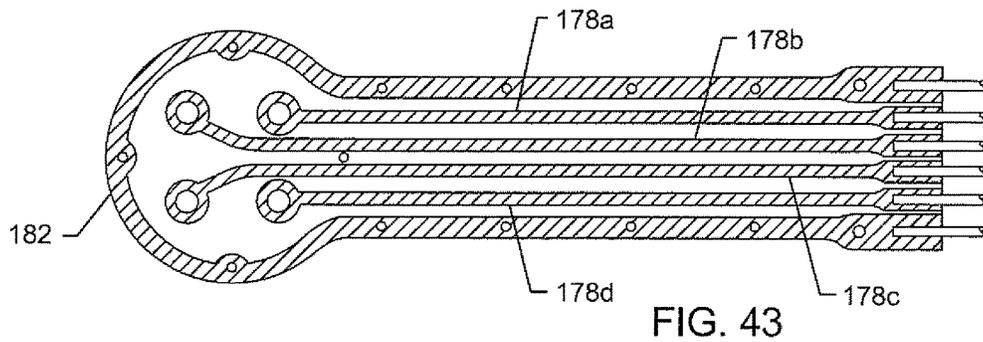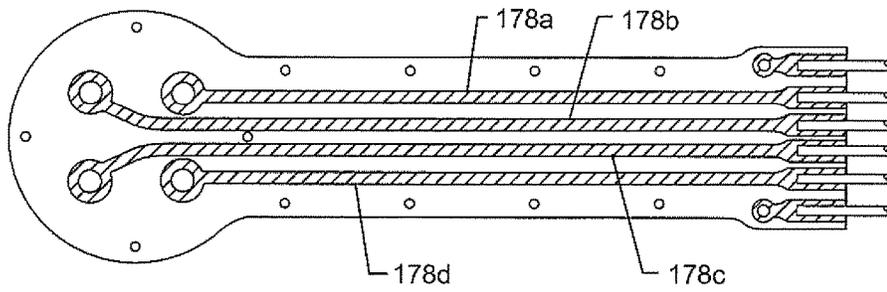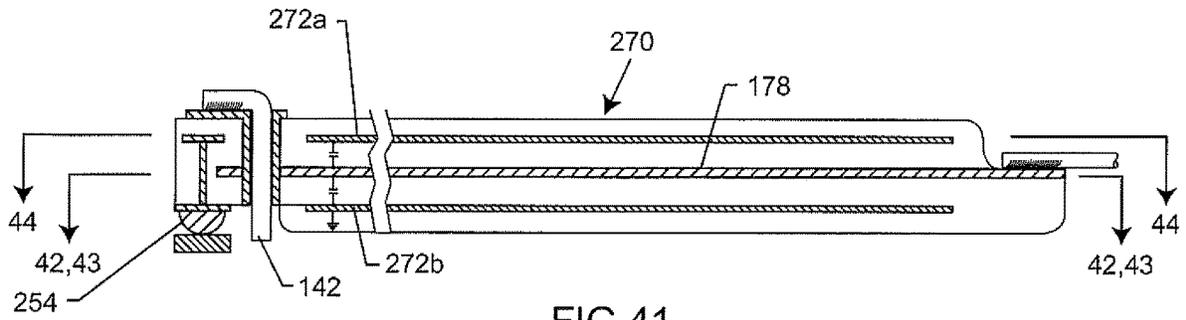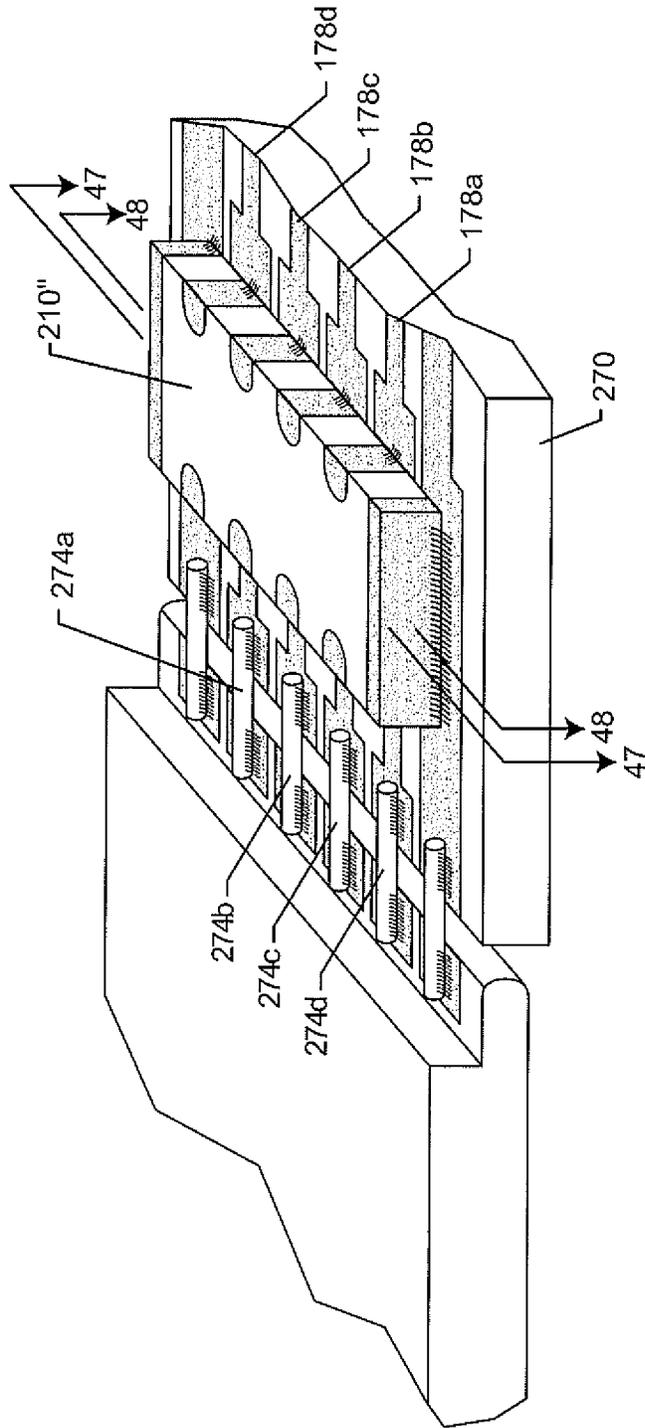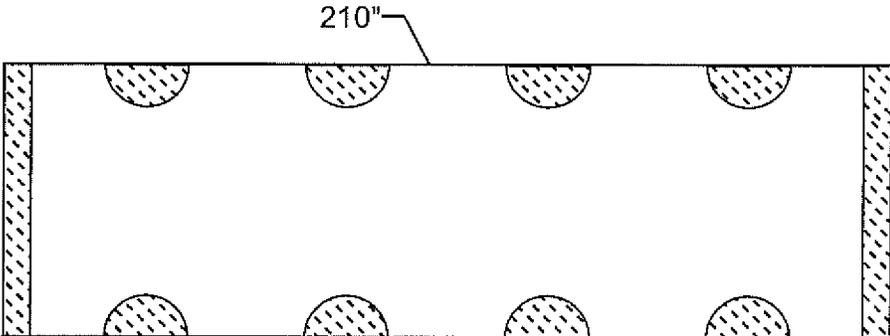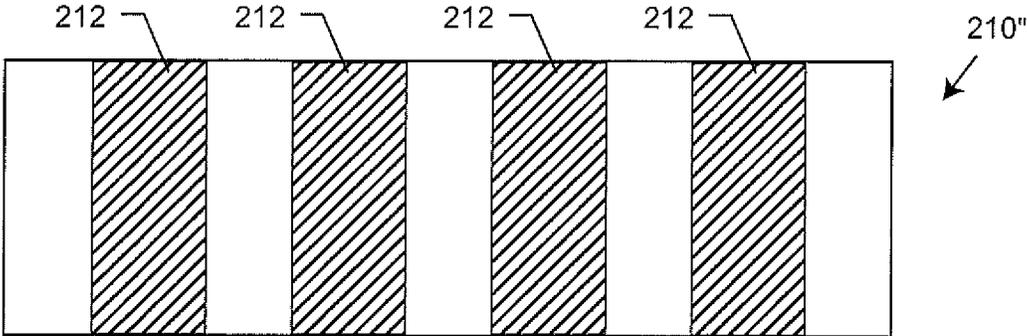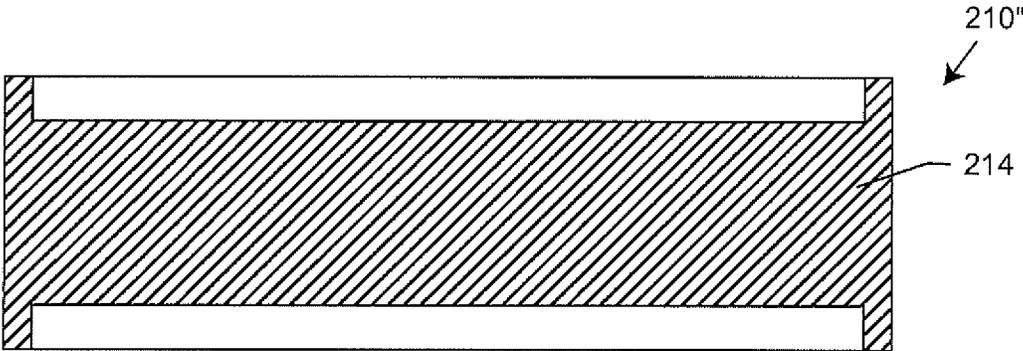
FIG. 48
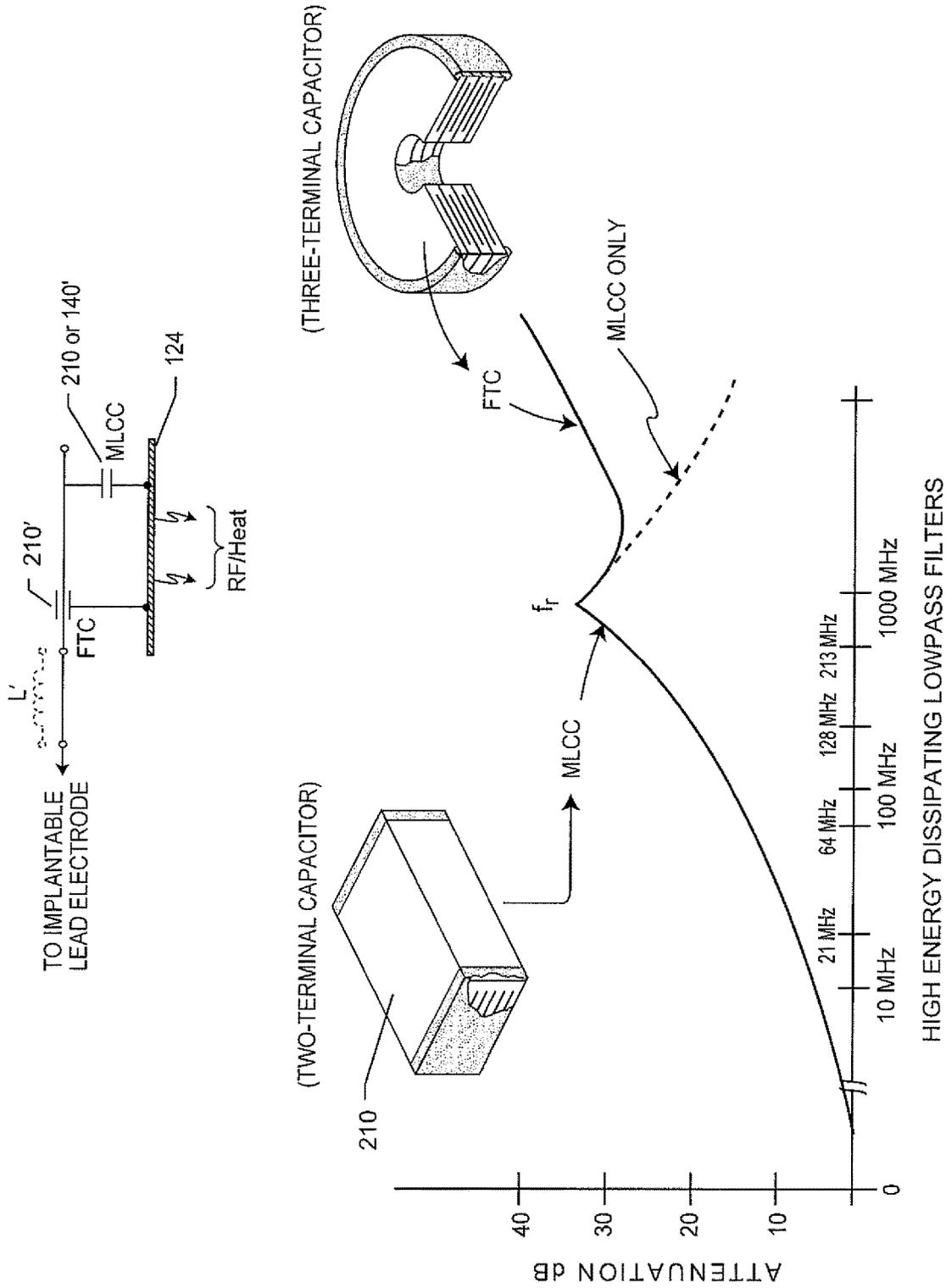
HIGH ENERGY DISSIPATING LOWPASS FILTERS

FIG. 49

FIG. 49A

FIG. 50

FIG. 51

FIG. 52

$\leq 0.5\,\Omega$

164a,174   164b,176

ESR

FIG. 53

DEVICE
SIDE

152

142a

142b

154a

210a

210b

152'

154b

156

134

136a

136b

BODY
FLUID
SIDE

FIG. 54

DEVICE/INBOARD SIDE
TO AIMD CIRCUITS

142a

142b

FIG. 55

210a

210b

134,124

134,124

HERMETIC
SEAL

136a

136b

BODY FLUID SIDE

FIG. 56

TO DISTAL
LEAD
ELECTRODE

TO AIMD
ELECTRONICS

210a

L_P

124

RF ENERGY/HEAT

210b

L_P

124

RF ENERGY/HEAT

210c

L_P

124

RF ENERGY/HEAT

210d

L_P

124

RF ENERGY/HEAT
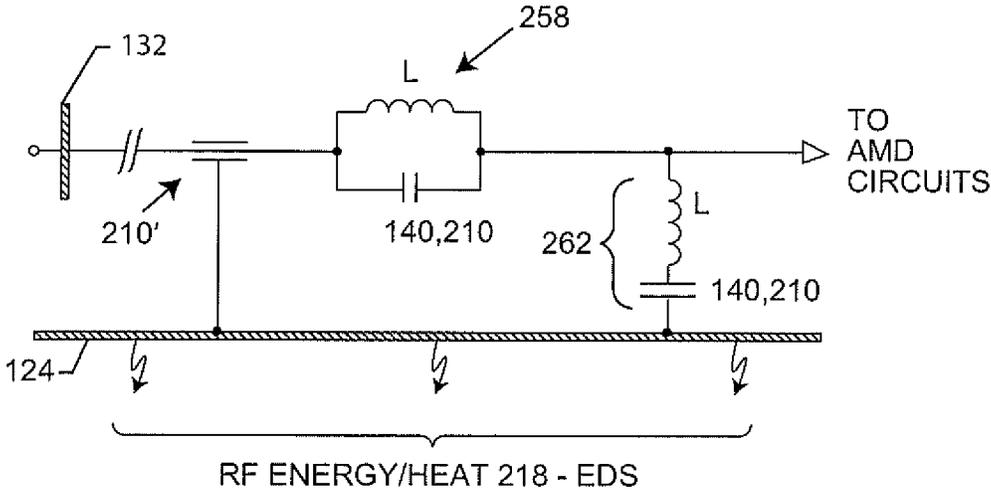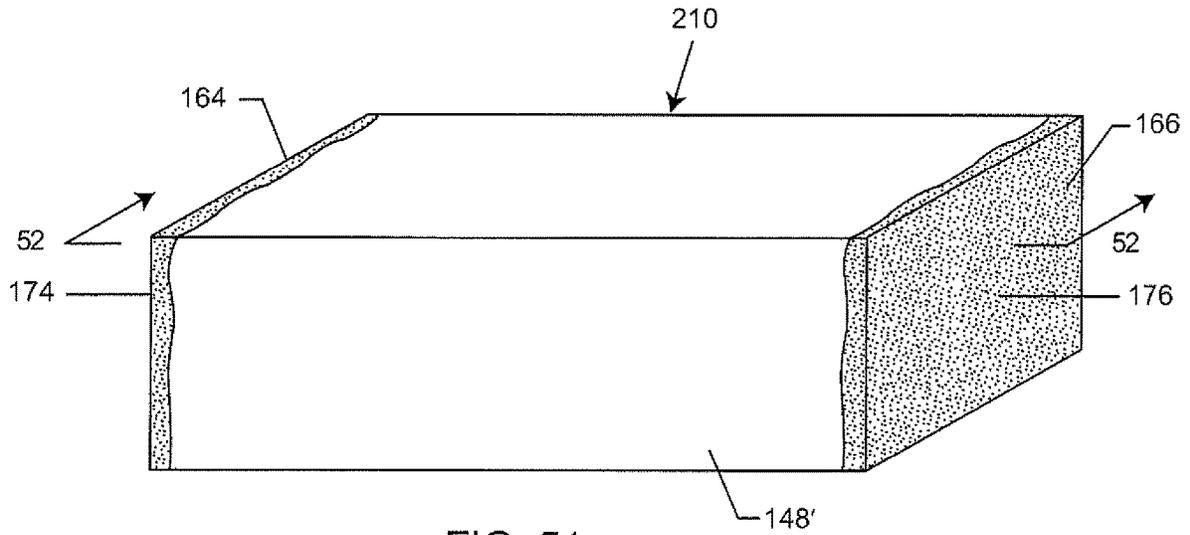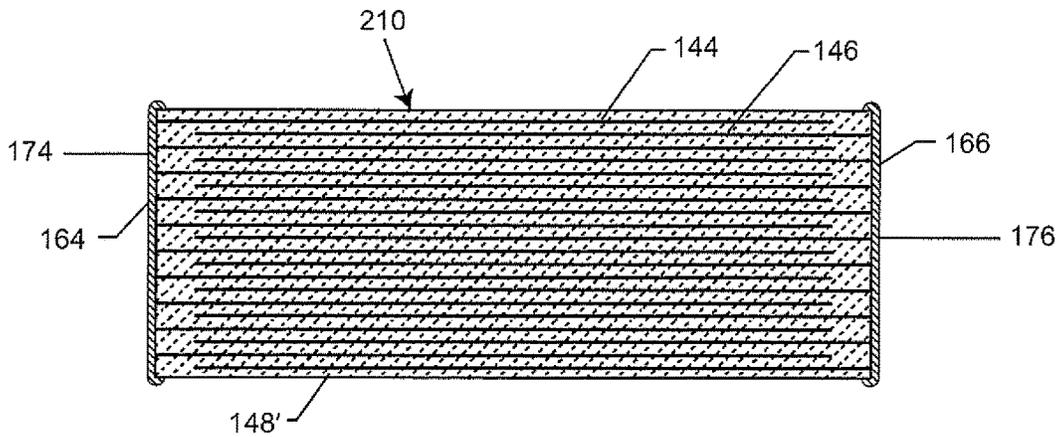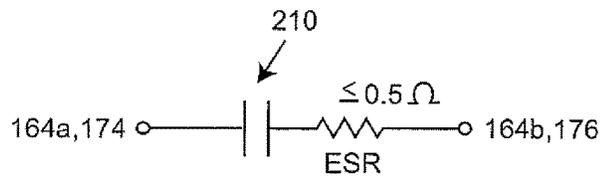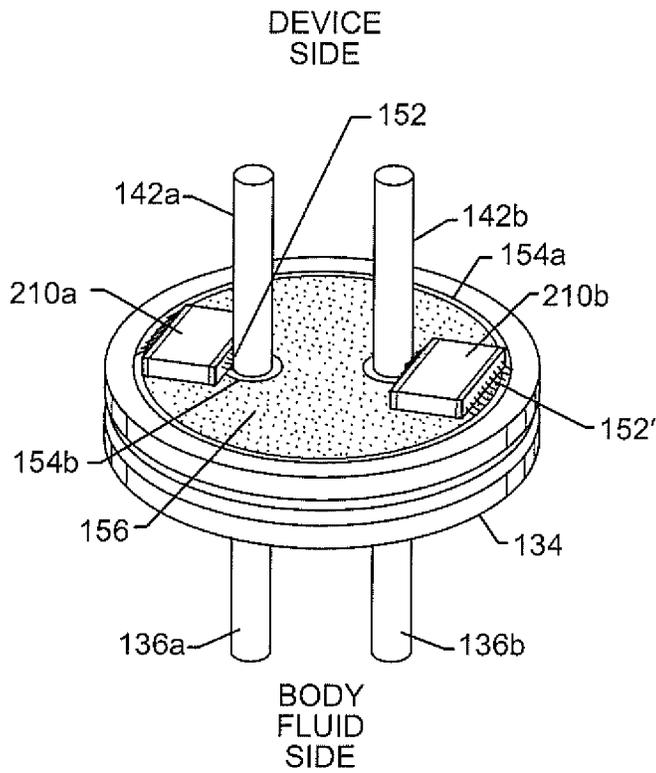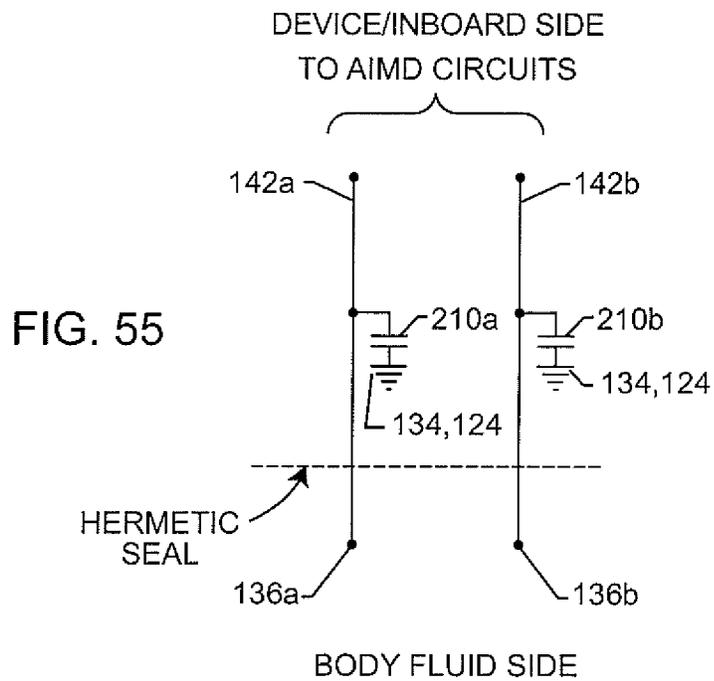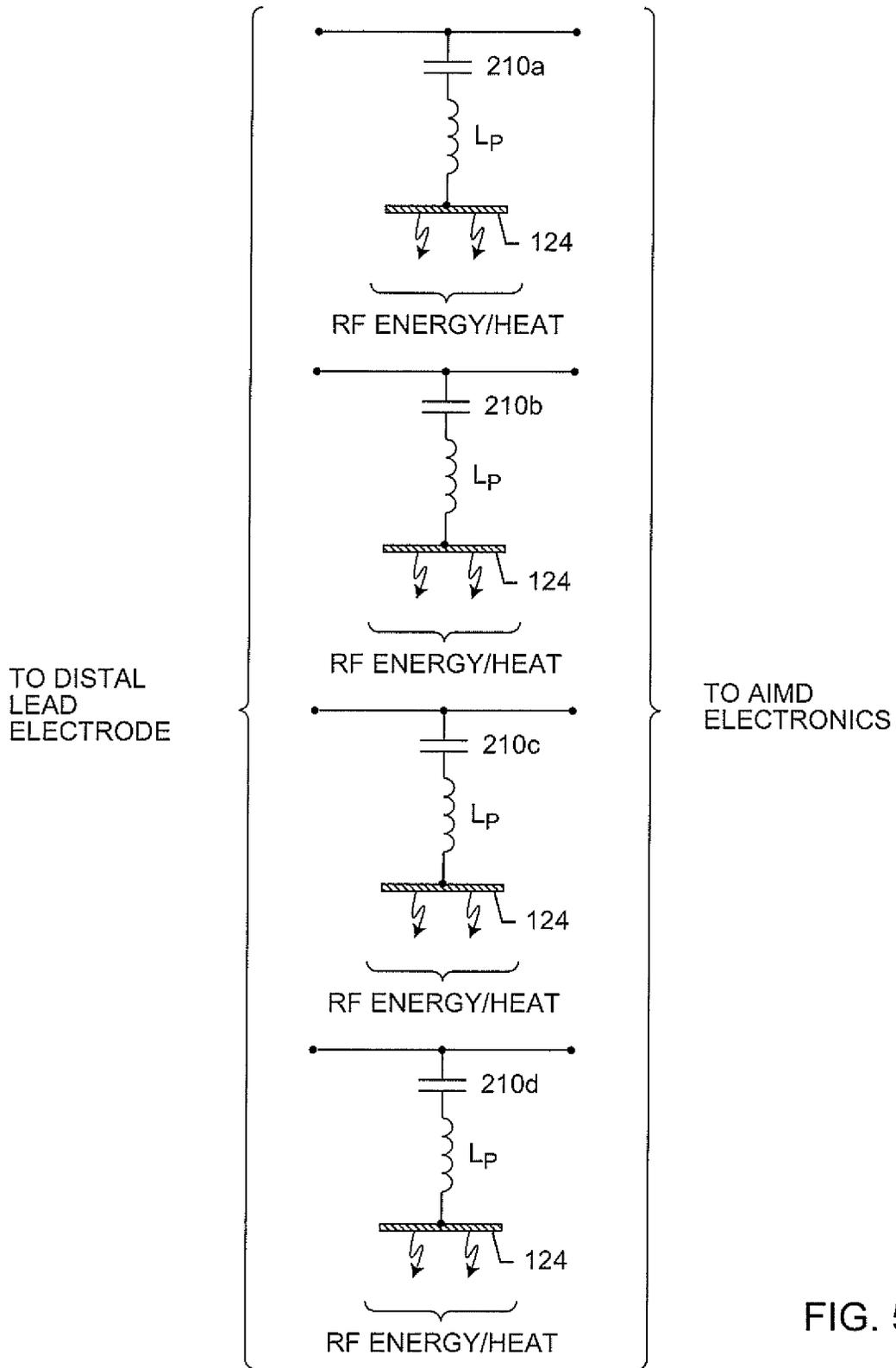
FIG. 56A
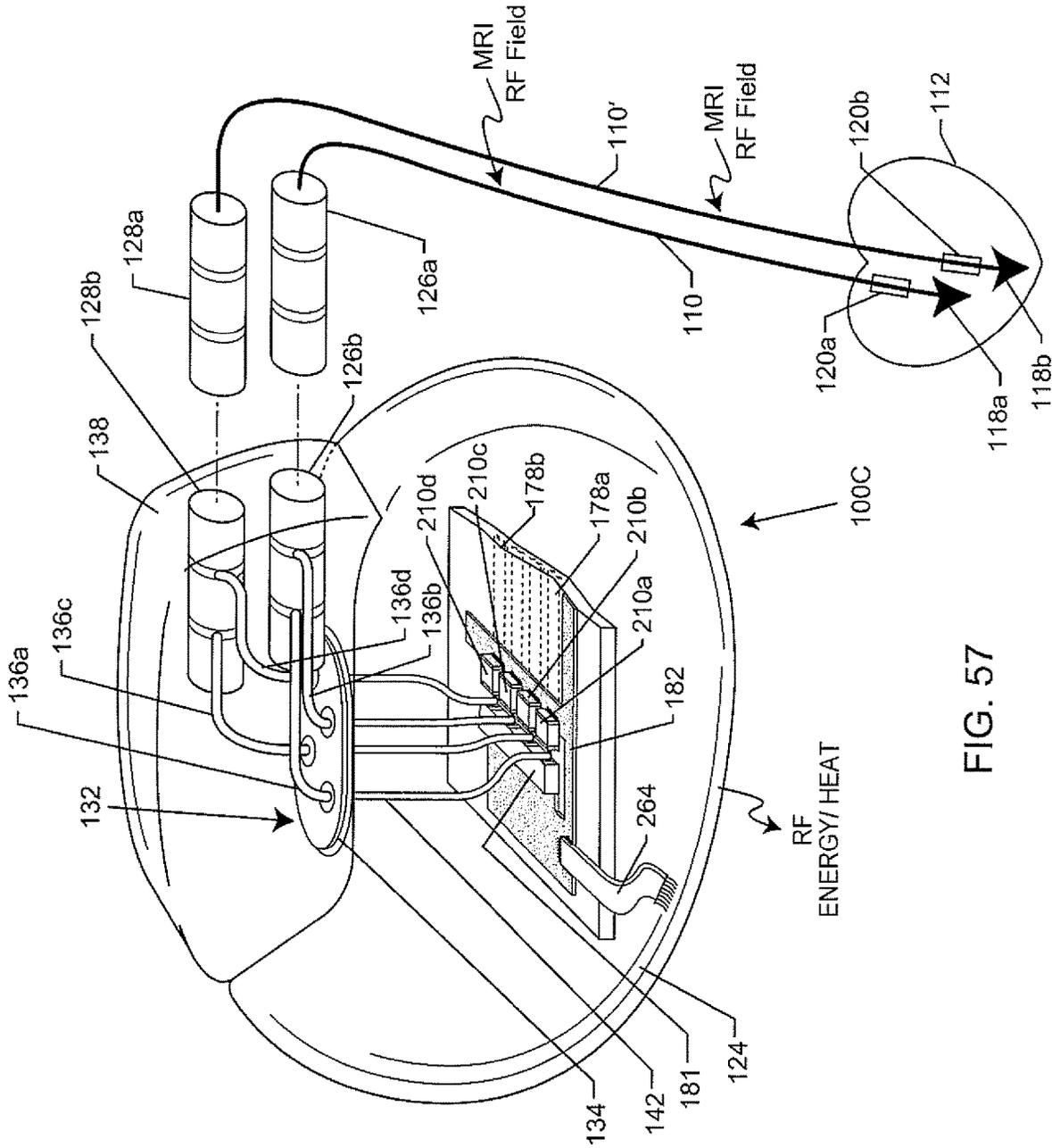
FIG. 57
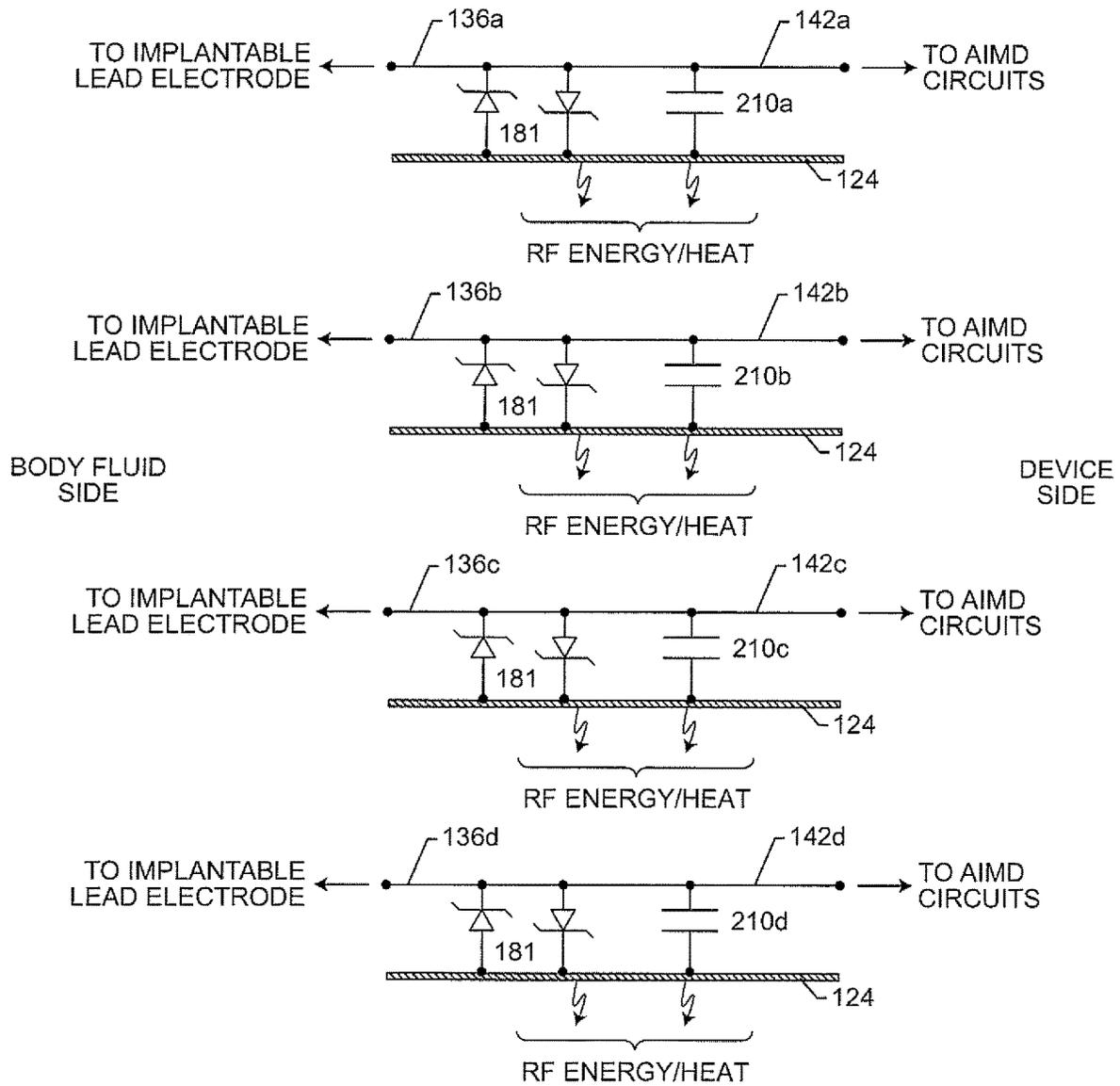
FIG. 58
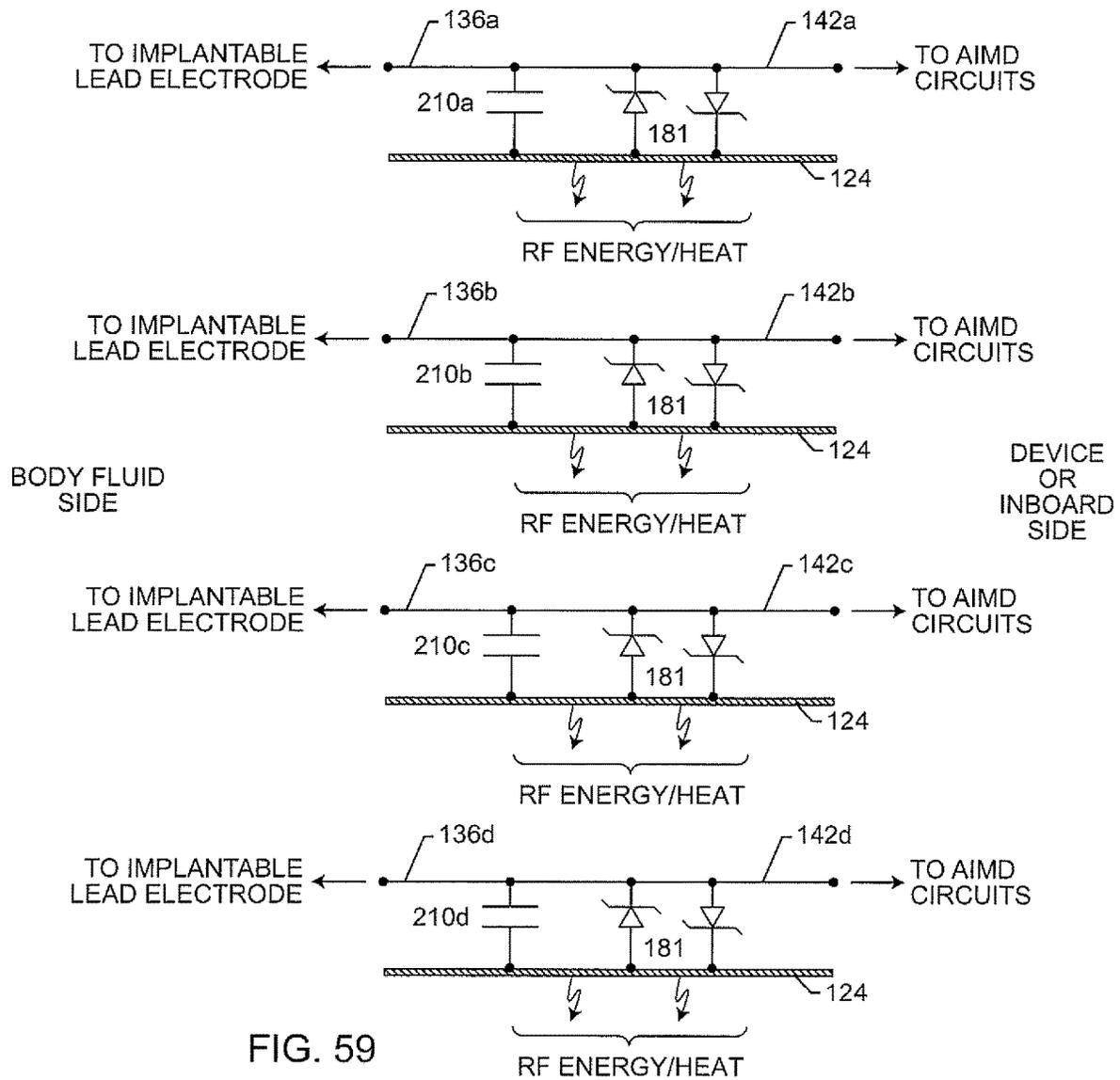
FIG. 59
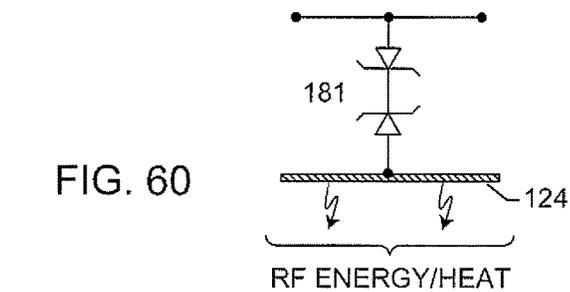
FIG. 60

FIG. 61

FIG. 62

FIG. 63

FIG. 64

BODY
FLUID
SIDE

EMI

DEVICE
SIDE

① 178a

L

146

L

② 178b

i_{1a},180 →

i_g ↓

144

—146

○ i_{1b},180 →

210″

134
③

FIG. 64A

(TOP VIEW OF DEVICE SIDE)
FIG. 64B

FIG. 64C

164d

148

64E

210''

164a

164d'

166

164a'

64E

FIG. 64D

i_{1a} 164a   144   148   164d

166   166

i_{1b} 164a'   164d'   FIG. 64E

146   148

FIG. 64F

FIG. 65A

DEVICE SIDE

BODY FLUID SIDE

142d'

210"

152

248,250

142c'

203'

187
185

151

187
185

142b'

151

187
185

164a'

129

203

154b

142a'

142a

156

166

152

142gnd

134

164a

165

154a

FIG. 65B

164d

148

65D

210″int

166

164a

164d′

164a′

FIG. 65C

65D

164a

148

164d

144a

164a′

164d′

FIG. 65D

166

146

166

FIG. 65E

FIG. 65F

FIG. 65G

FIG. 65H
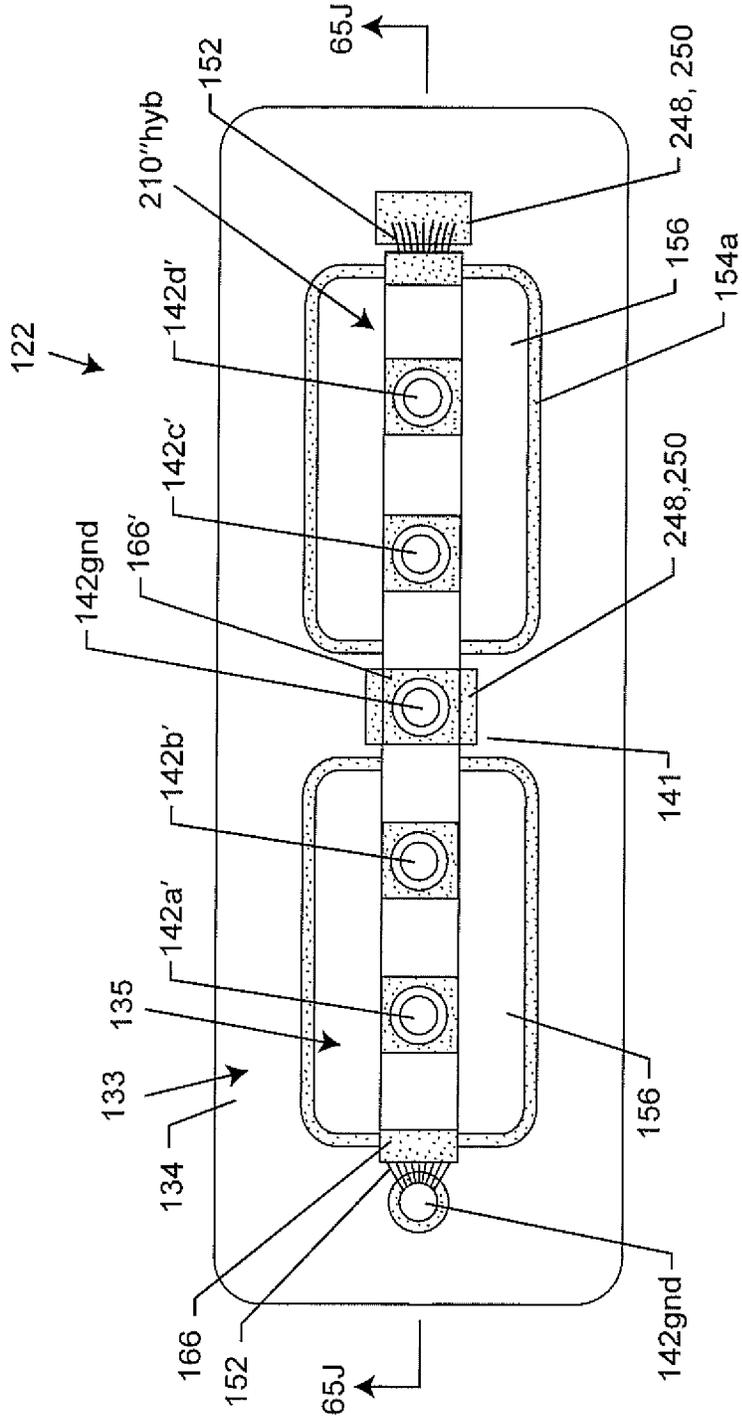
FIG. 65 I
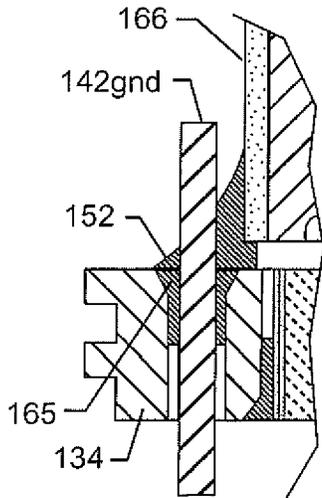
FIG. 65J
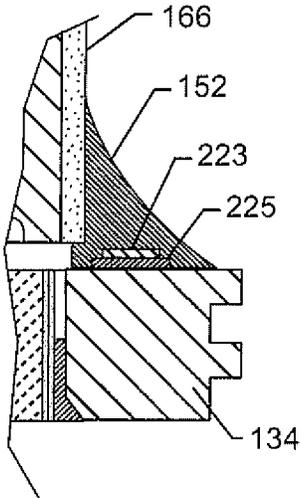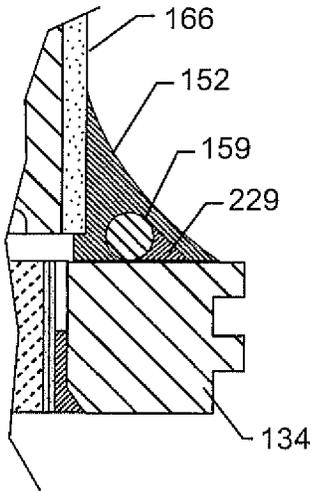
FIG. 65Ja

FIG. 65Jb

FIG. 65Jc

FIG. 65Jd

FIG. 65K

FIG. 65L

FIG. 65M

FIG. 65N

210"hyb

166

164a' 164b' 164c' 164d' 164e' 164f'

148

FIG. 65O

210"hyb

144a 144b 144c 144d 144e 144f

146

FIG. 65P

FIG. 65Q

DEVICE SIDE

BODY FLUID SIDE

FIG. 65R

FIG. 65S

FIG. 65T

FIG. 66

FIG. 67

FIG. 68
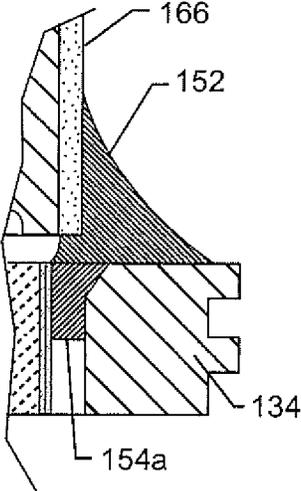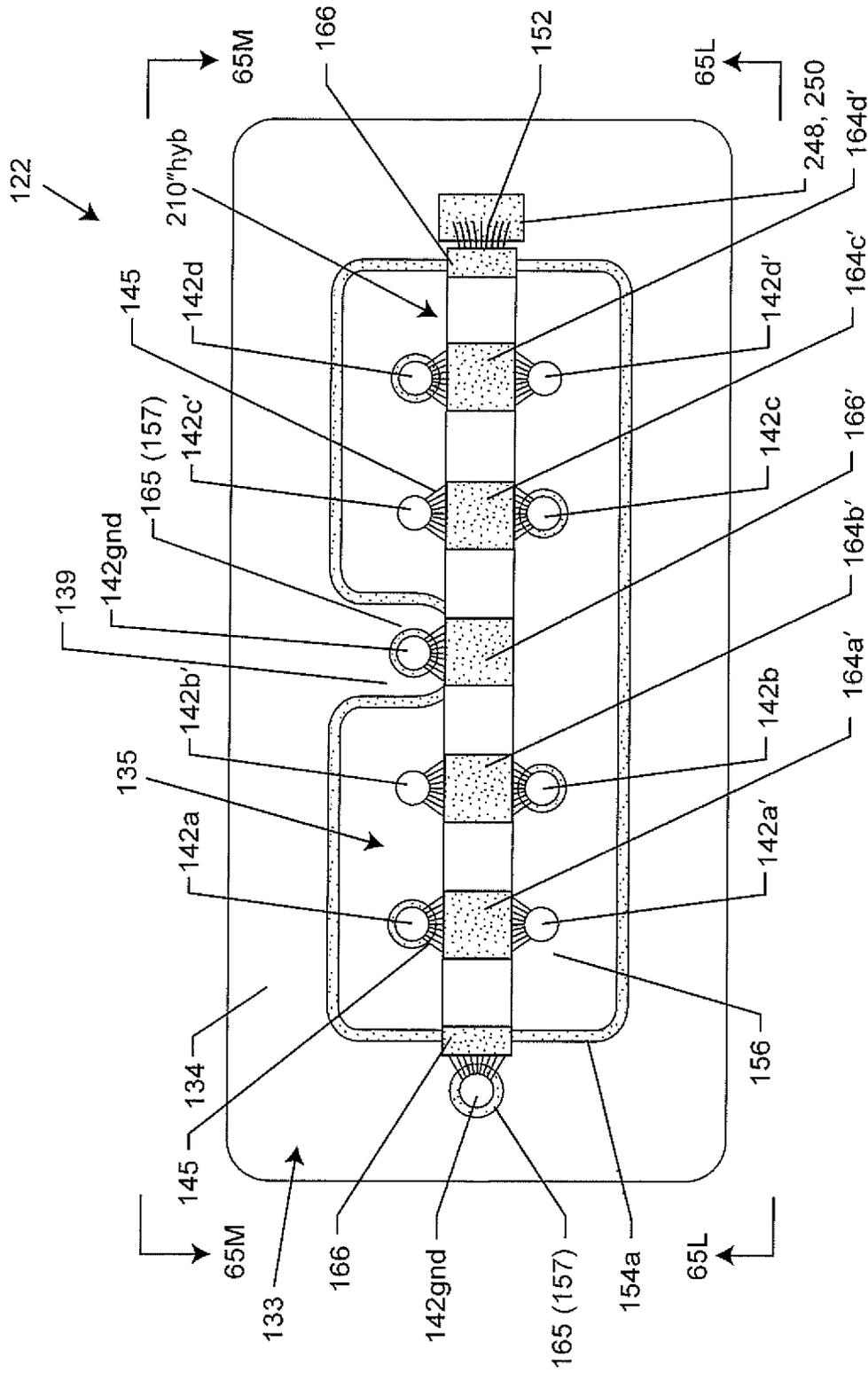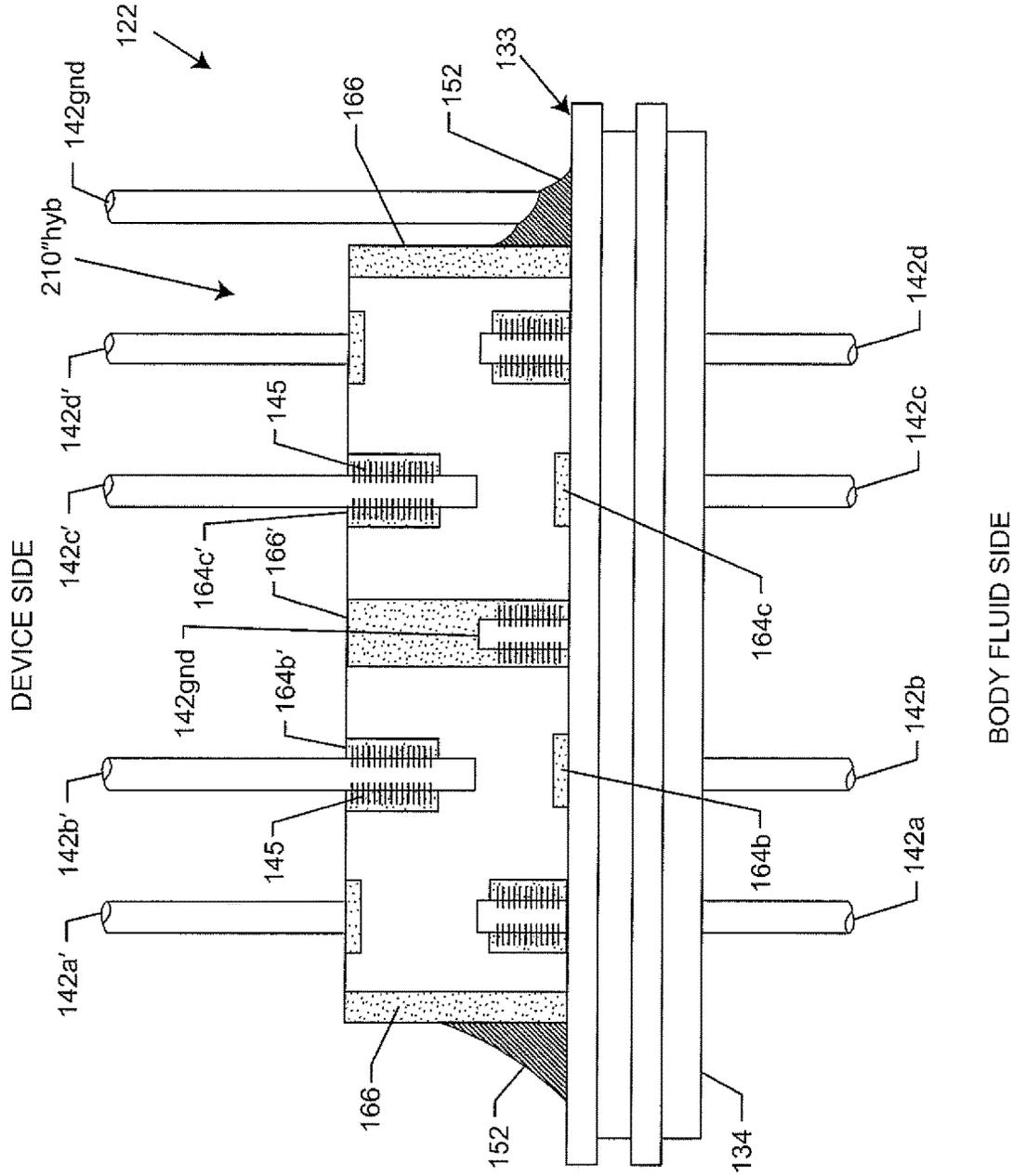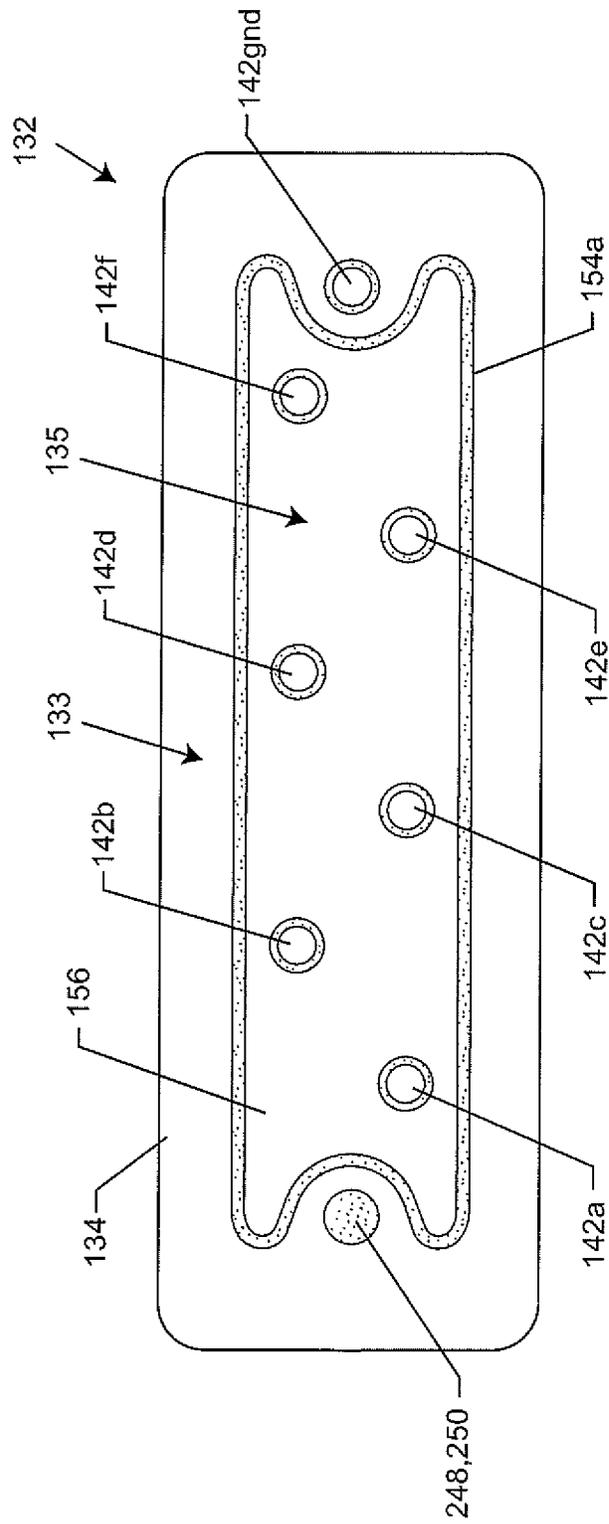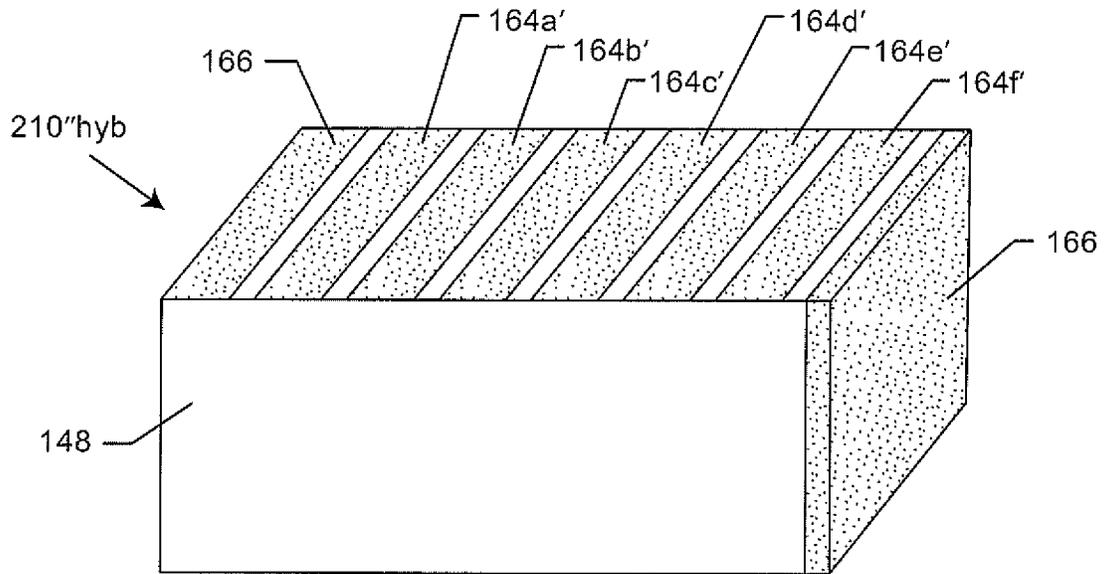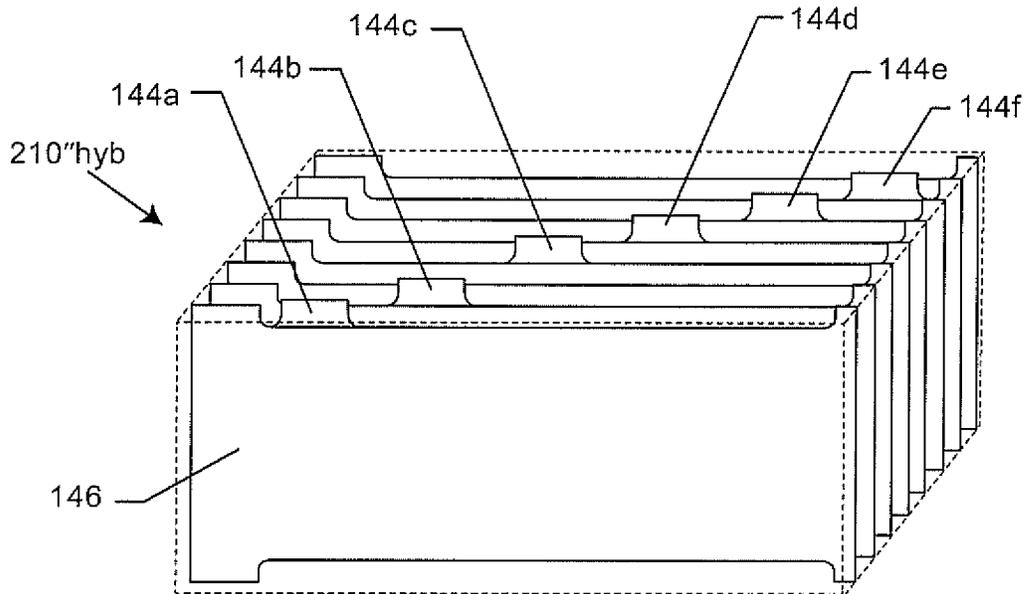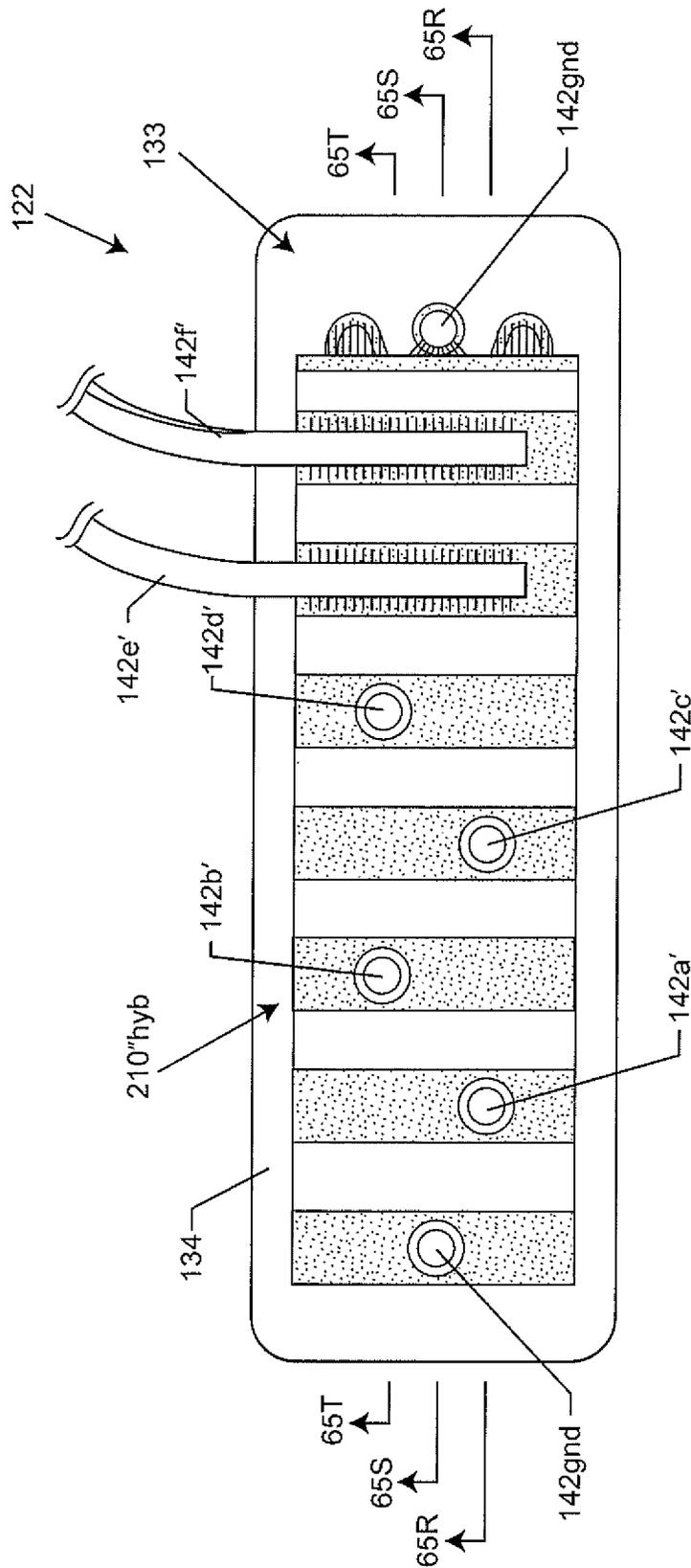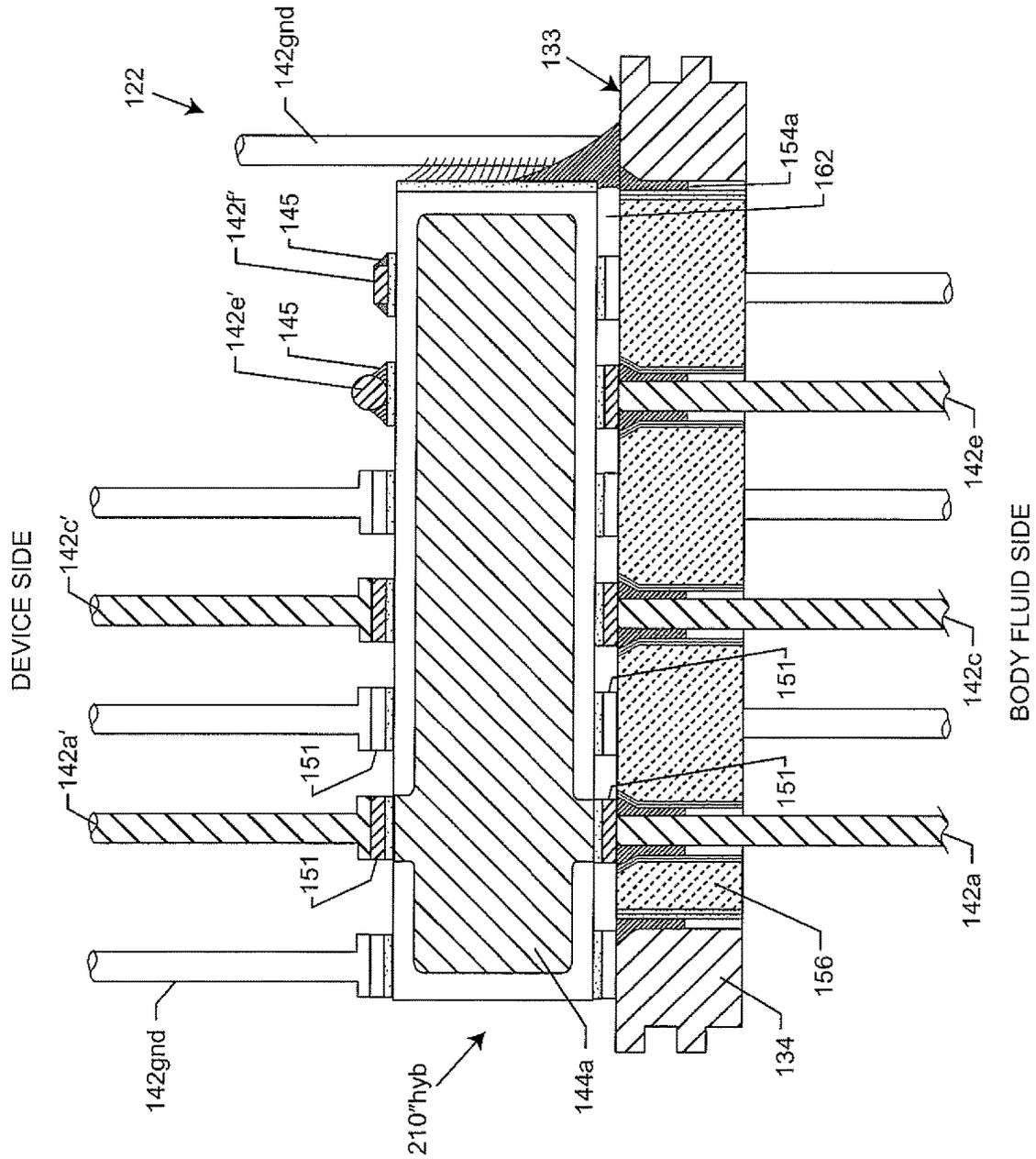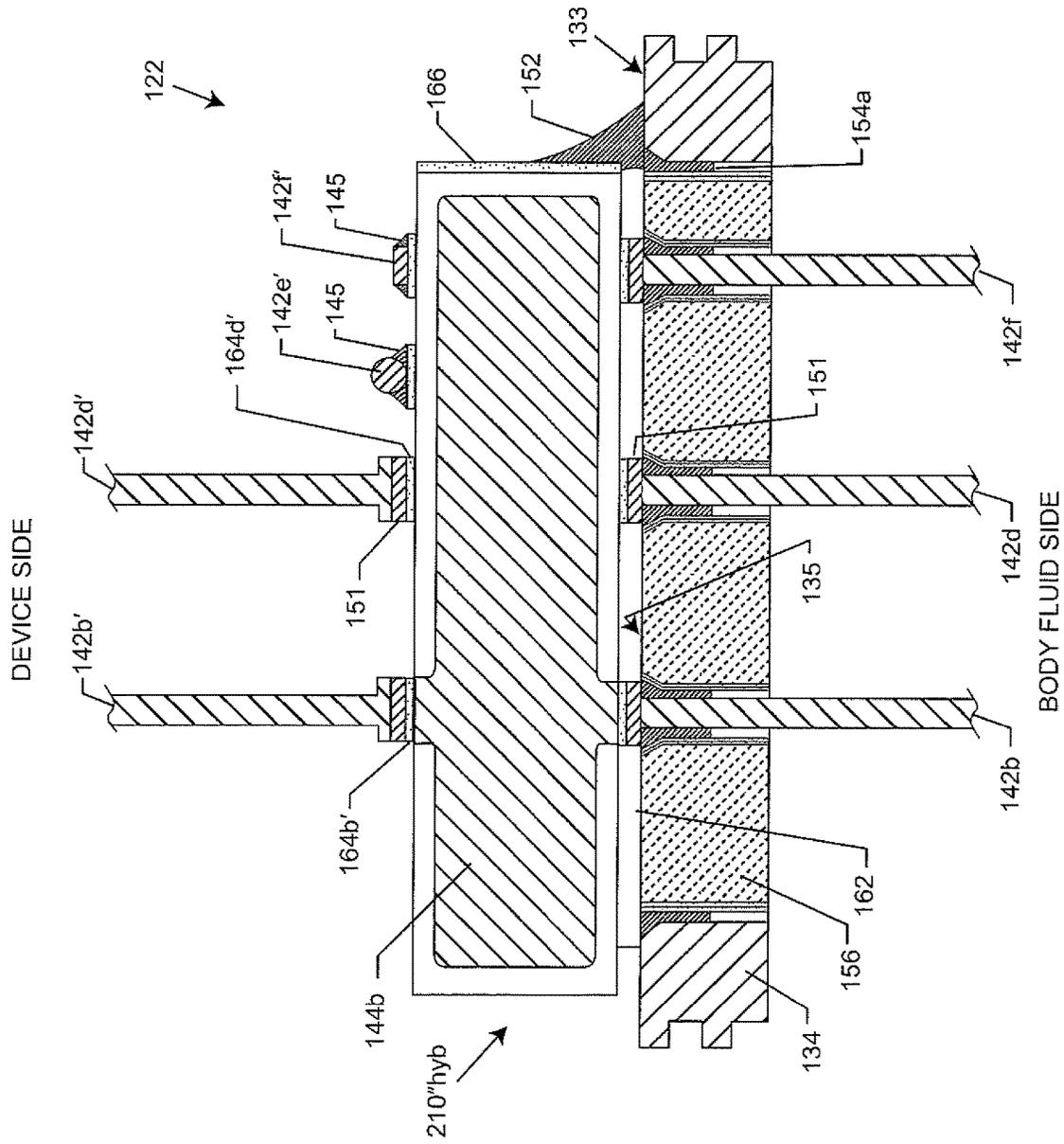
FIG. 69
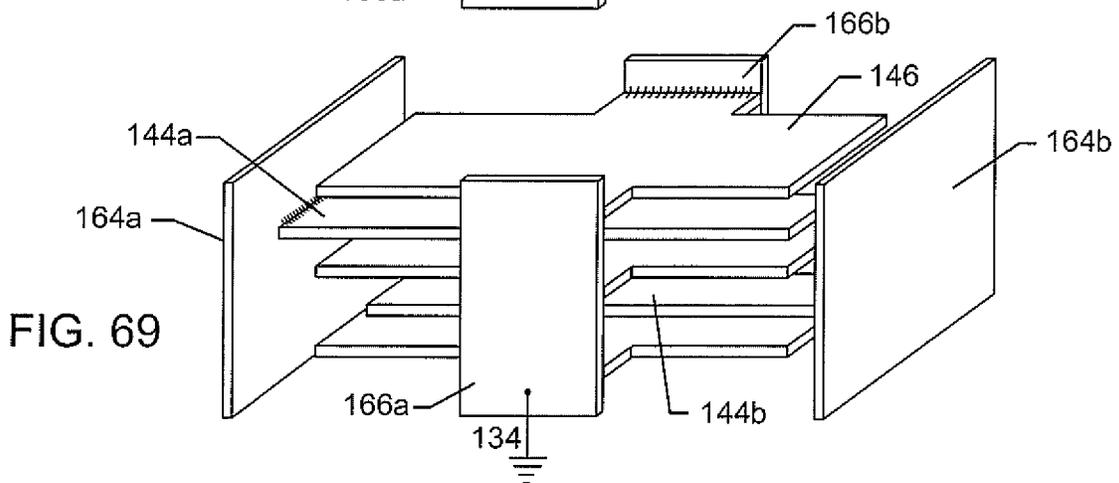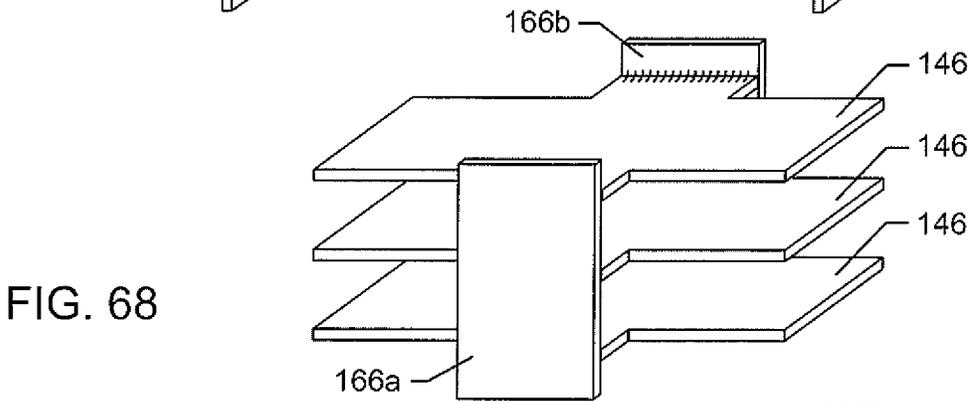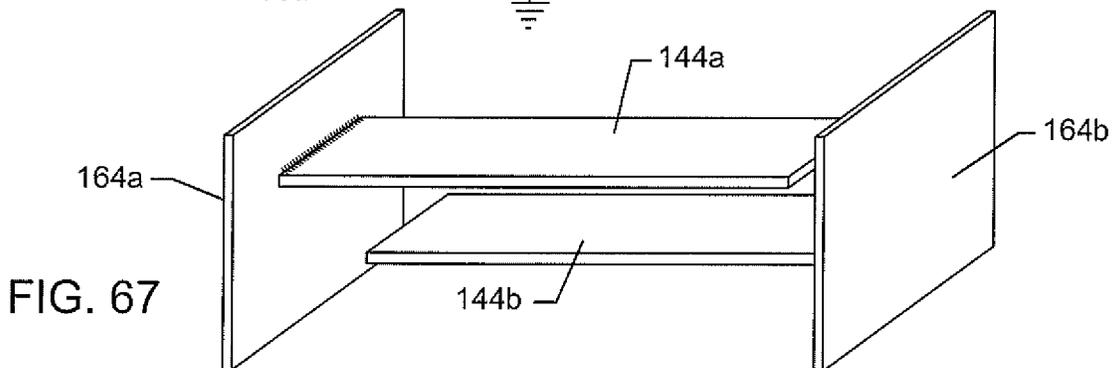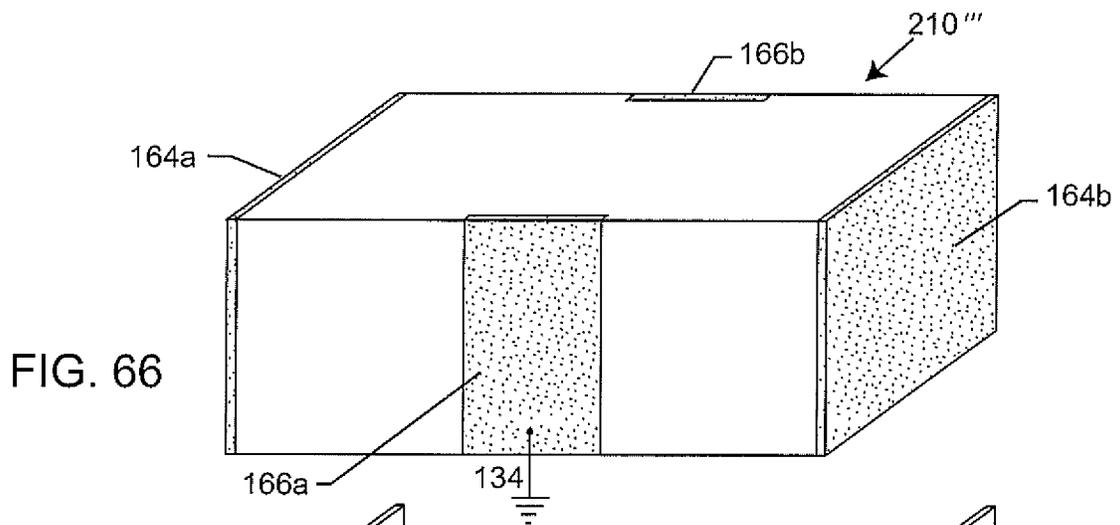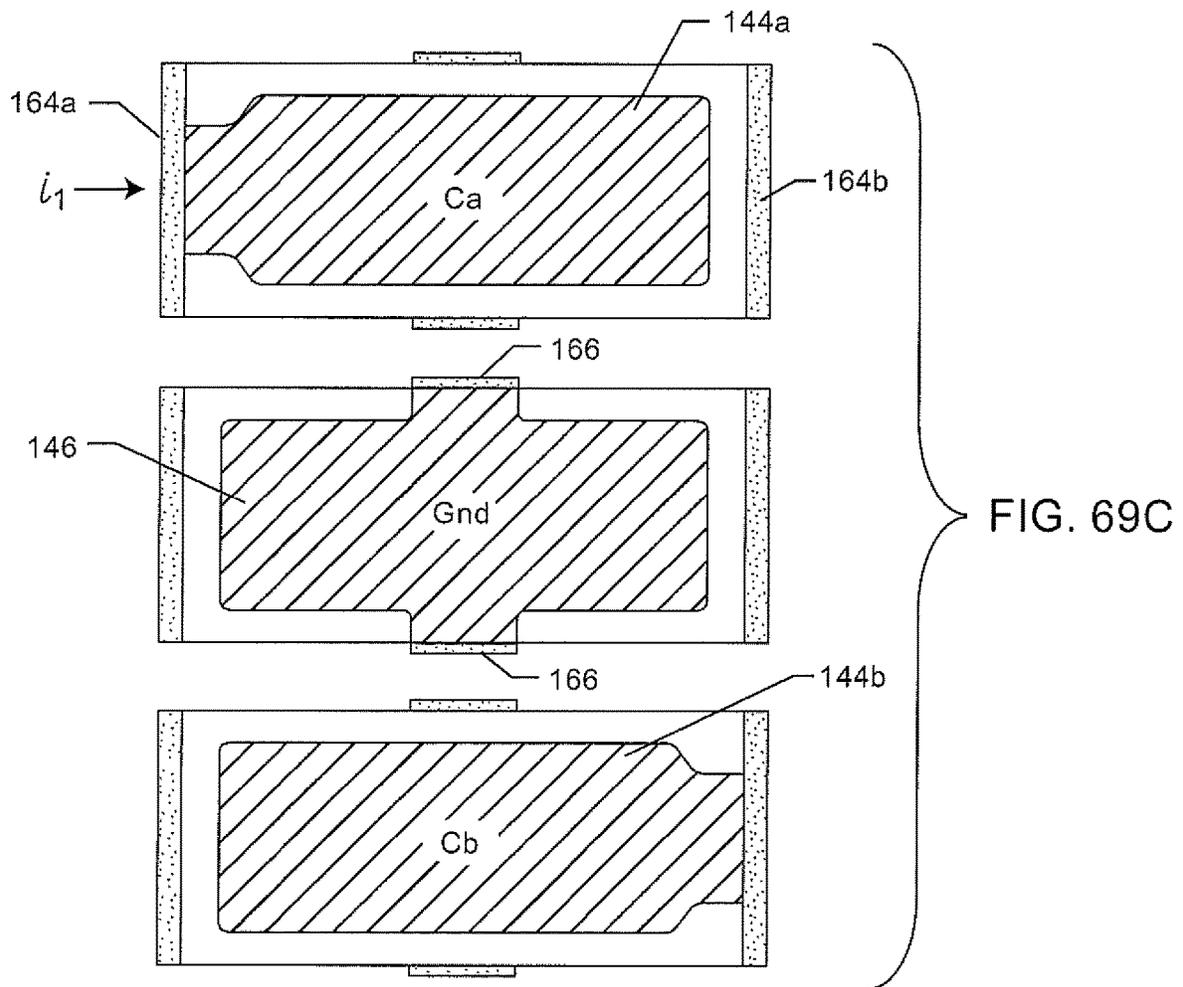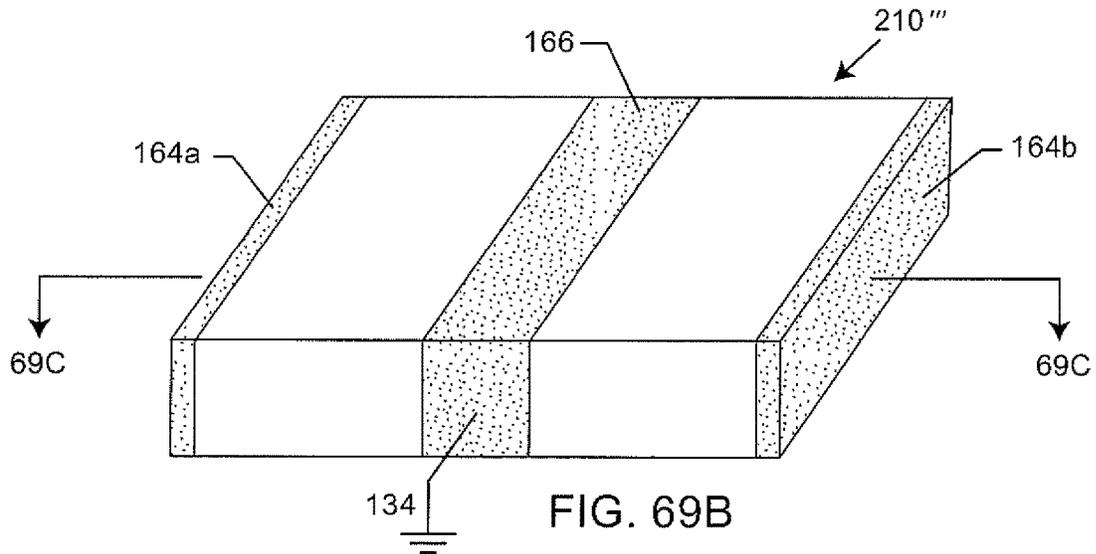
FIG. 69B

FIG. 69C

DEVICE OR BODY FLUID SIDE
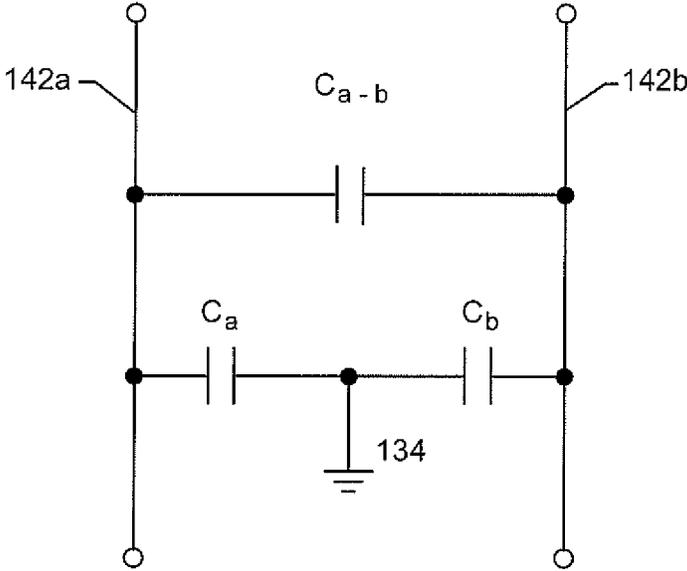
FIG. 69D
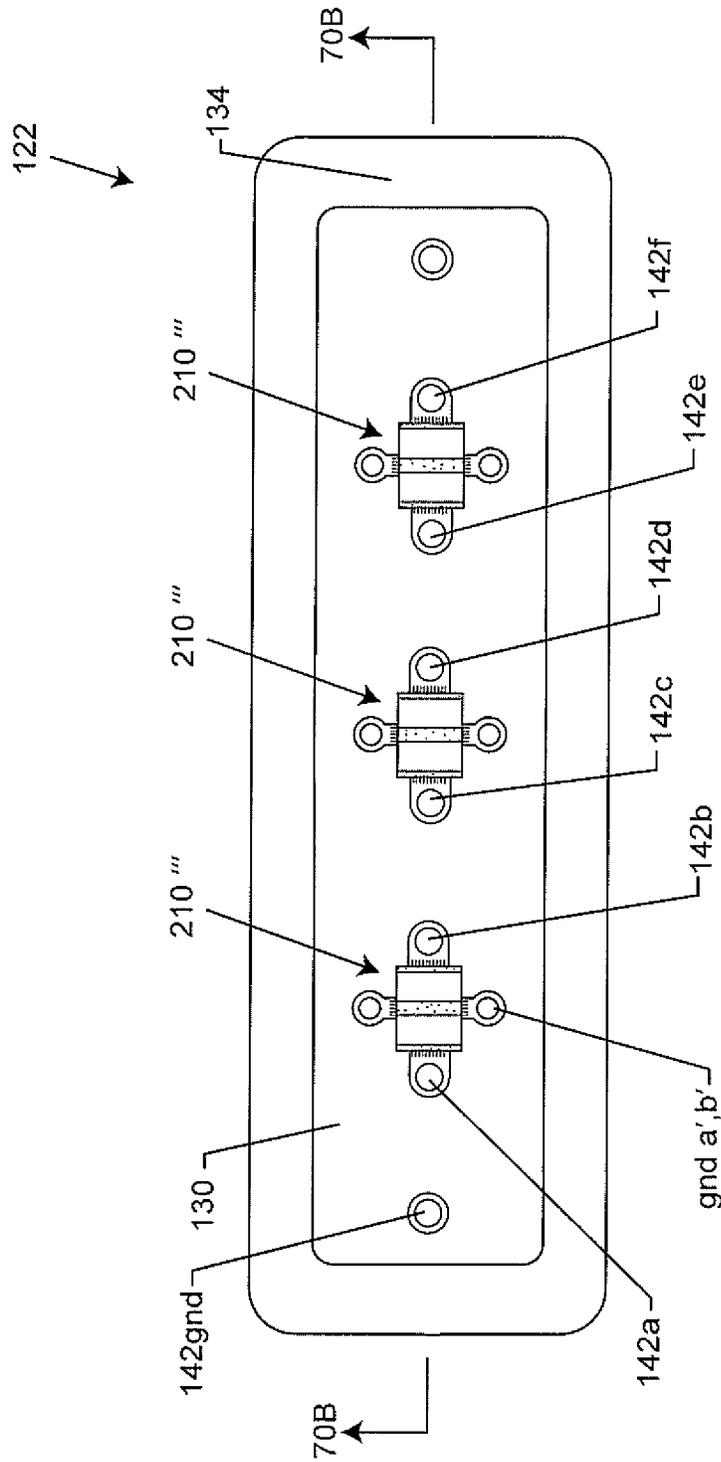
(TOP VIEW OF DEVICE SIDE)

FIG. 70A
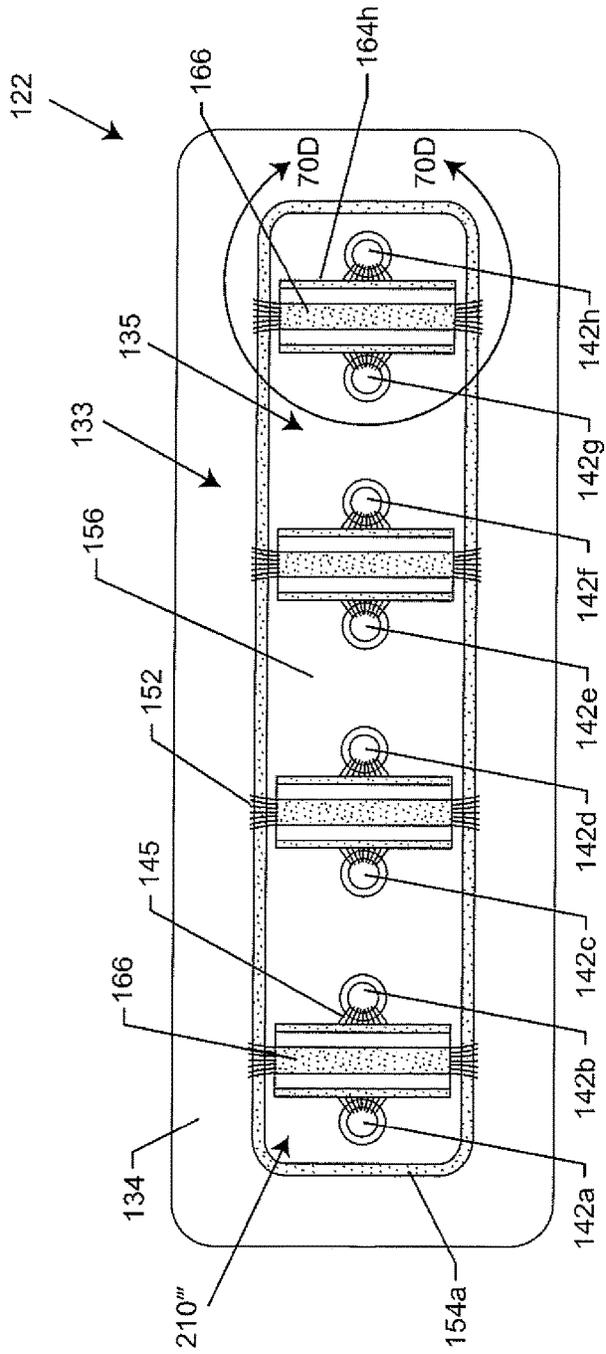
FIG. 70B
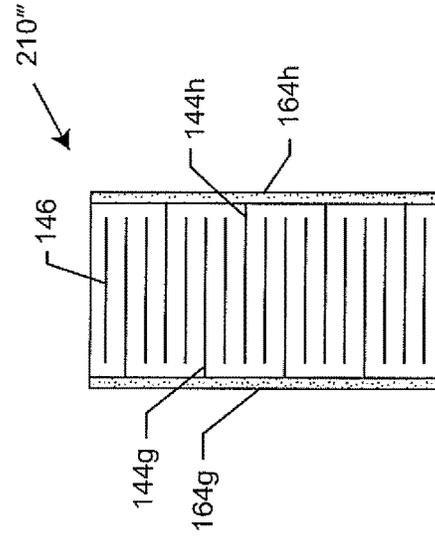
FIG. 70C

FIG. 70D
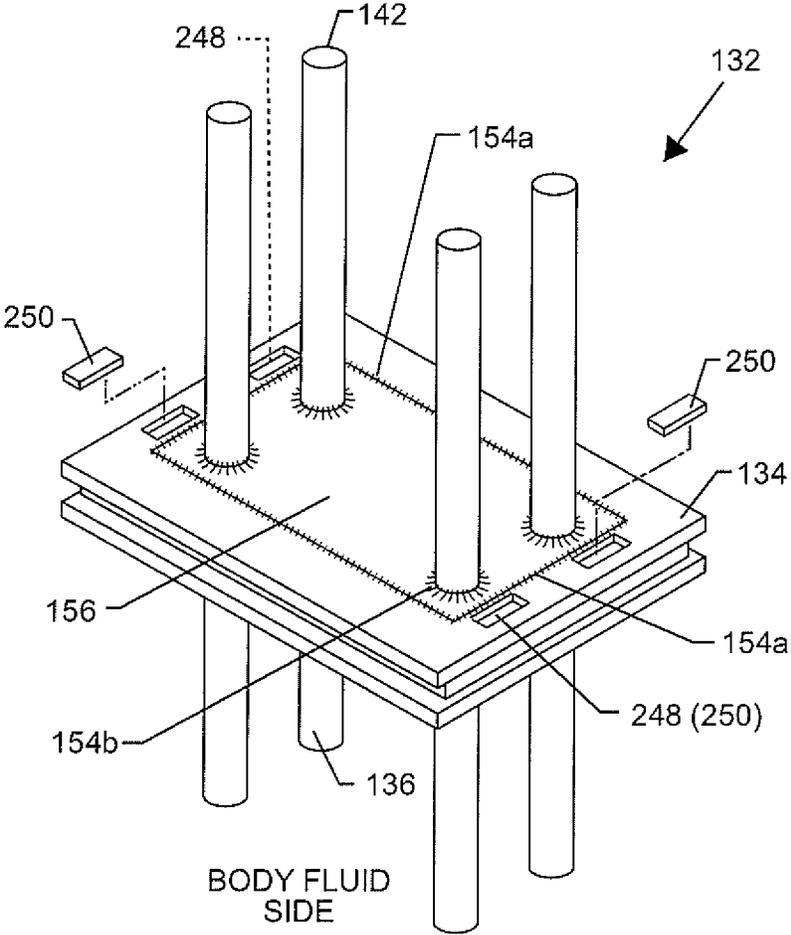
FIG. 71A

BODY FLUID
SIDE

FIG. 71B

BODY FLUID
SIDE

FIG. 71C

DEVICE SIDE

BODY FLUID
SIDE

FIG. 72A

DEVICE SIDE

BODY FLUID
SIDE

FIG. 72B

DEVICE SIDE

BODY FLUID
SIDE

FIG. 72C

DEVICE SIDE

BODY FLUID
SIDE

FIG. 73

Device Side

144h

146

144h

146

144a

144a

Device Side

166

210'i

NO PERIMETER
(OR DIAMETER)
METALLIZATION164

INTERNAL
GROUND
LEAD 142gnd

T

154a
134

156

Body Fluid Side

FIG. 74A
PRIOR ART

142h

INTERNAL
GROUND
LEAD 142gnd

142a

T

139

136h

156

136a

Body Fluid Side

134

FIG.74B
PRIOR ART

142h
132
210'i

134

Device Side

INTERNAL
GROUND
LEAD 142gnd

142a

T

136h

NO
EXTERNAL
ELECTRICAL
CONNECTION

136a

Body Fluid Side

FIG. 74C
PRIOR ART
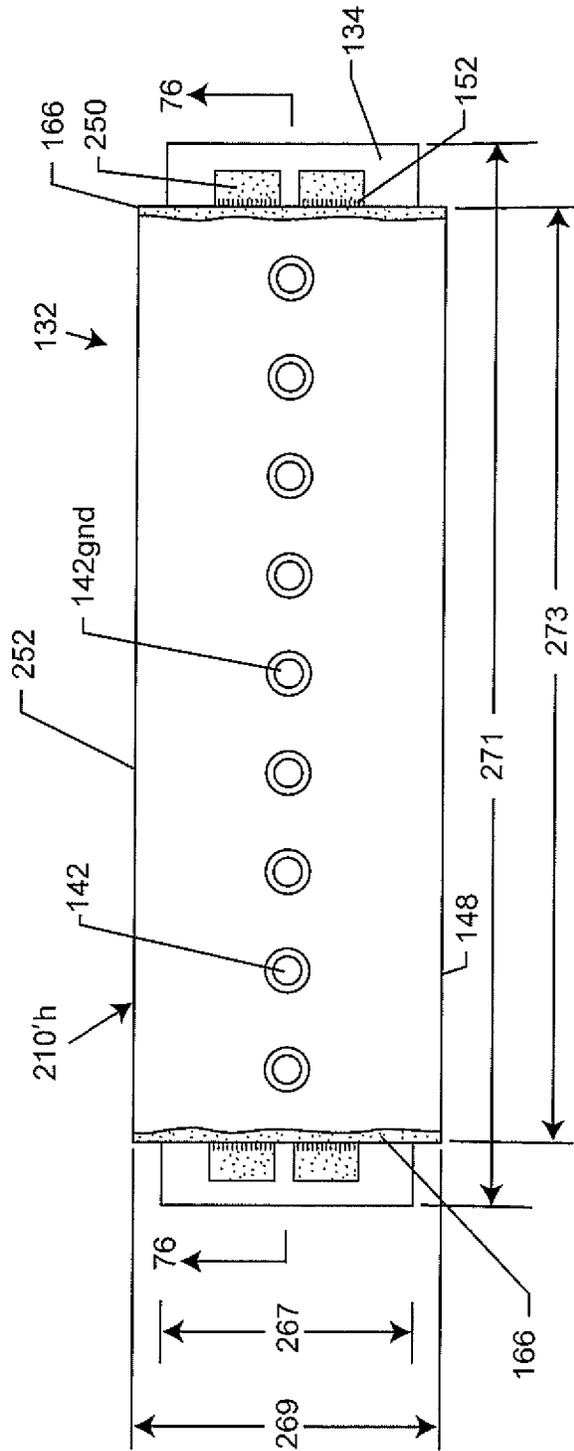
FIG. 75
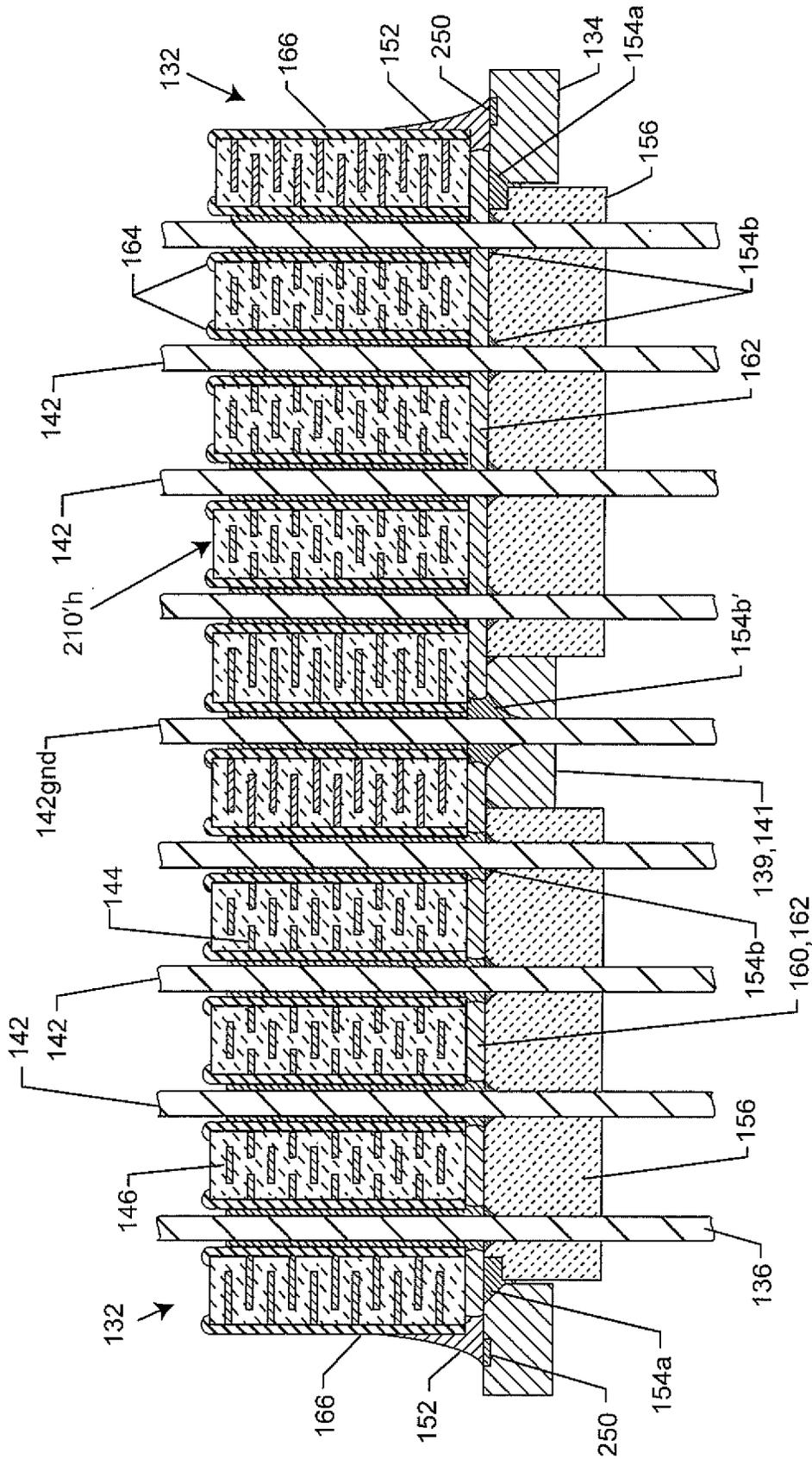
BODY FLUID SIDE

FIG. 76

FIG. 77

FIG. 78

FIG. 79

FIG. 80

FIG. 81

FIG. 82

FIG. 83

FIG. 84

FIG. 85

Manufacturing
Process Steps

Alumina sheets

↓

Collate

↓

Laminate

Form Green Alumina
Insulator

Drill outer hole
of passageway

↓

Fill with CRMC

↓

Dry

↓

Drill inner hole

↓

Fill with Pt paste

↓

Pressing

↓

Singulate

↓

Firing Process
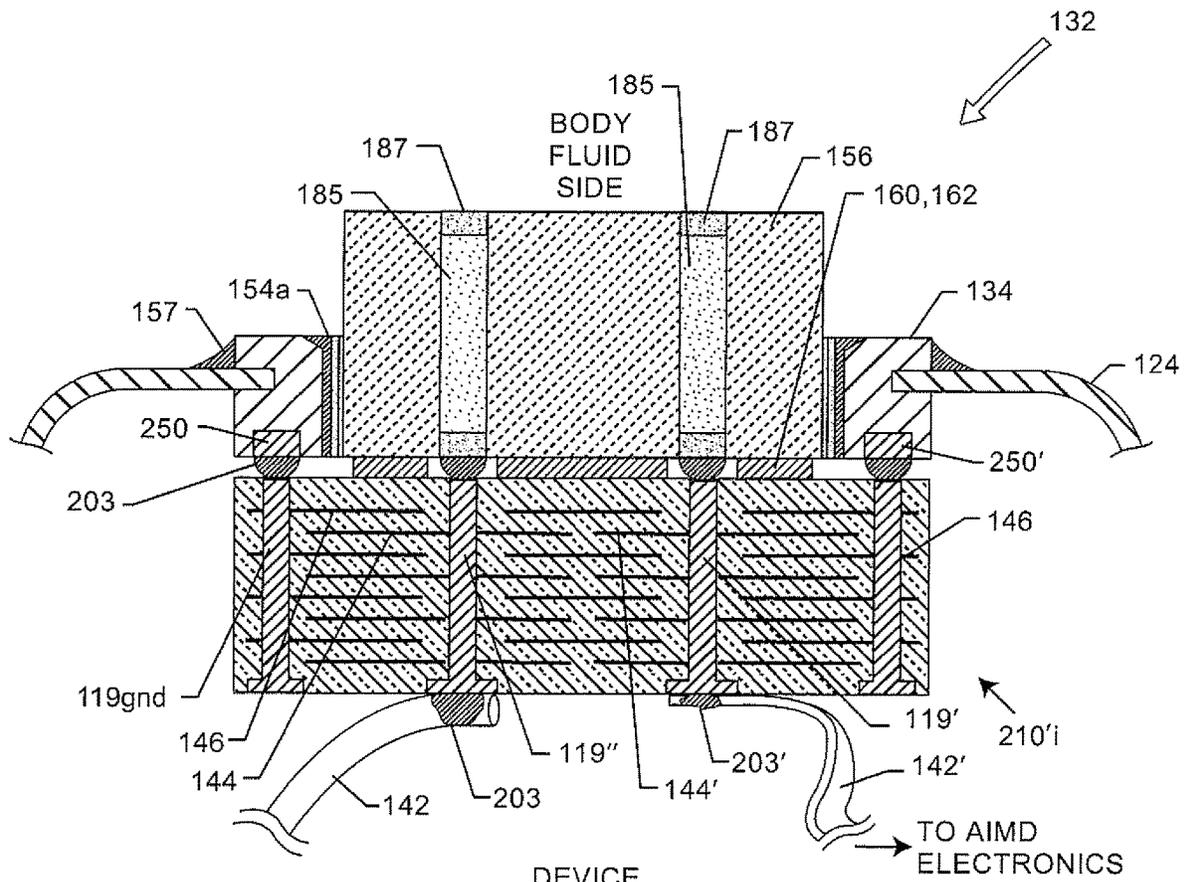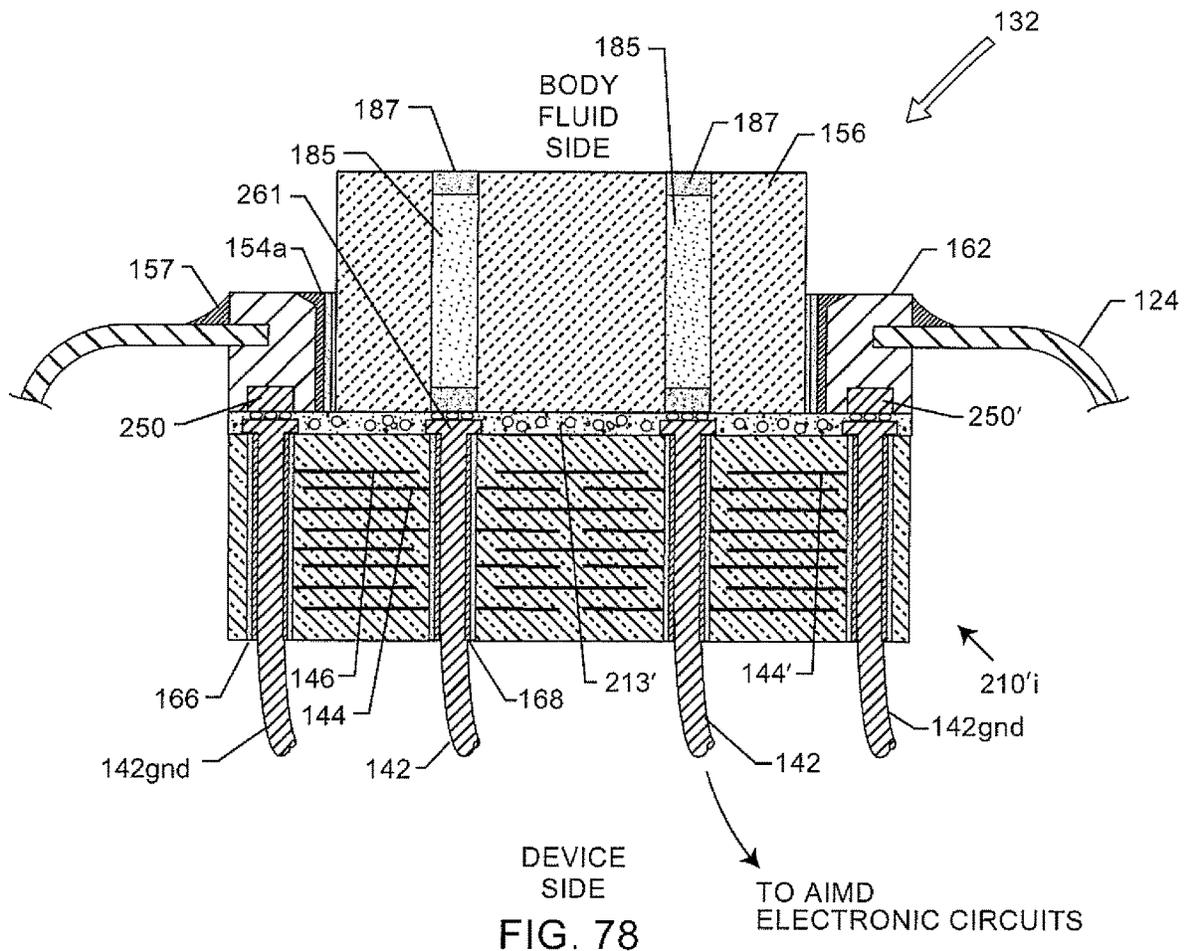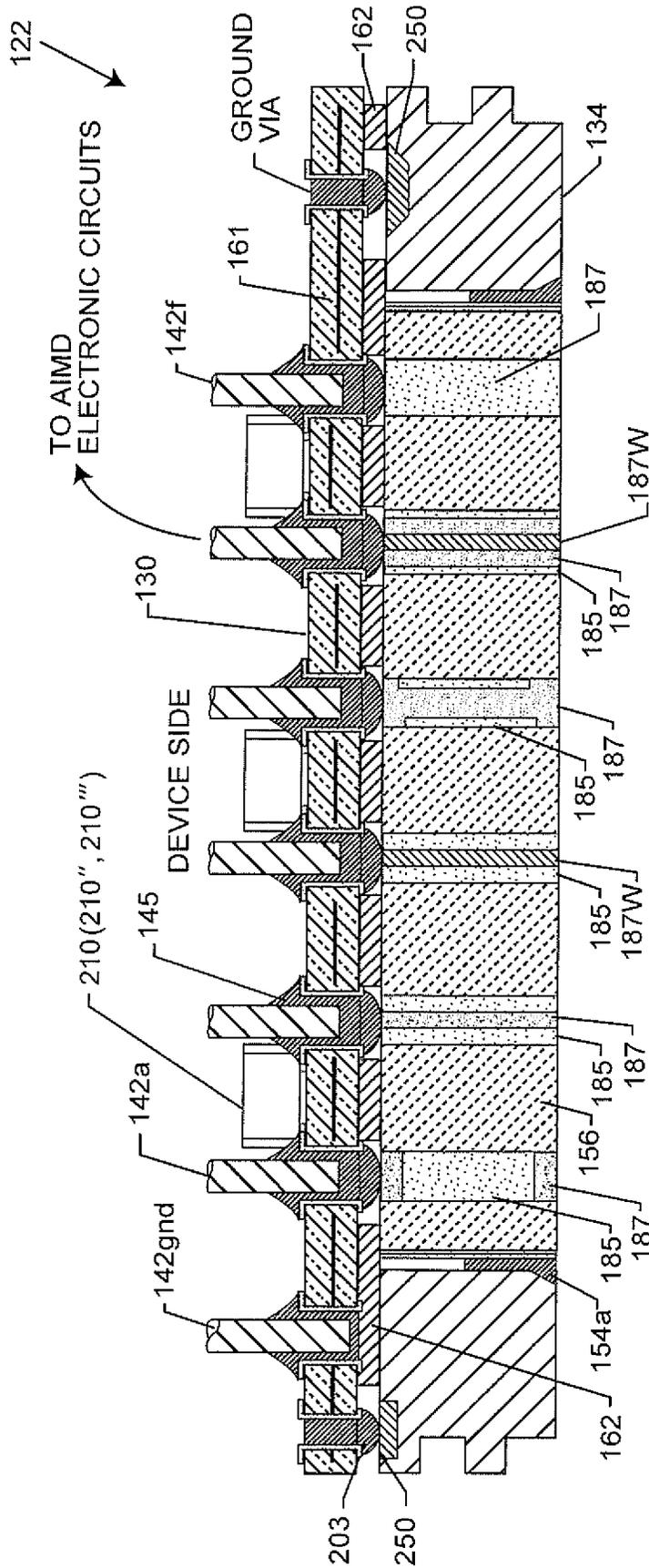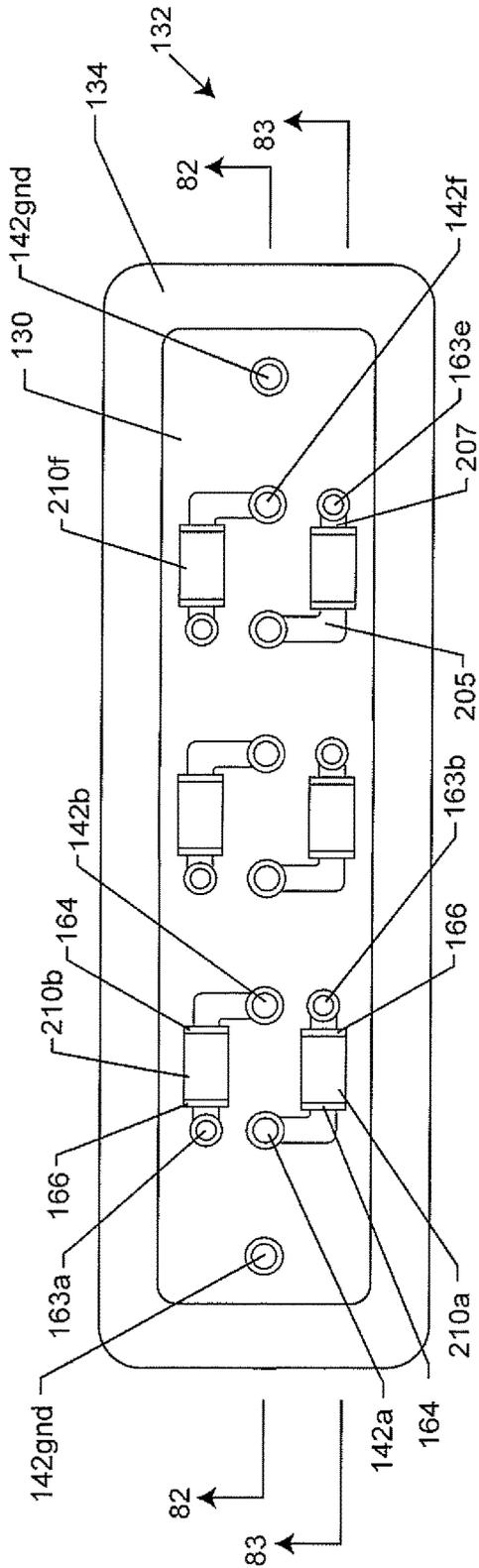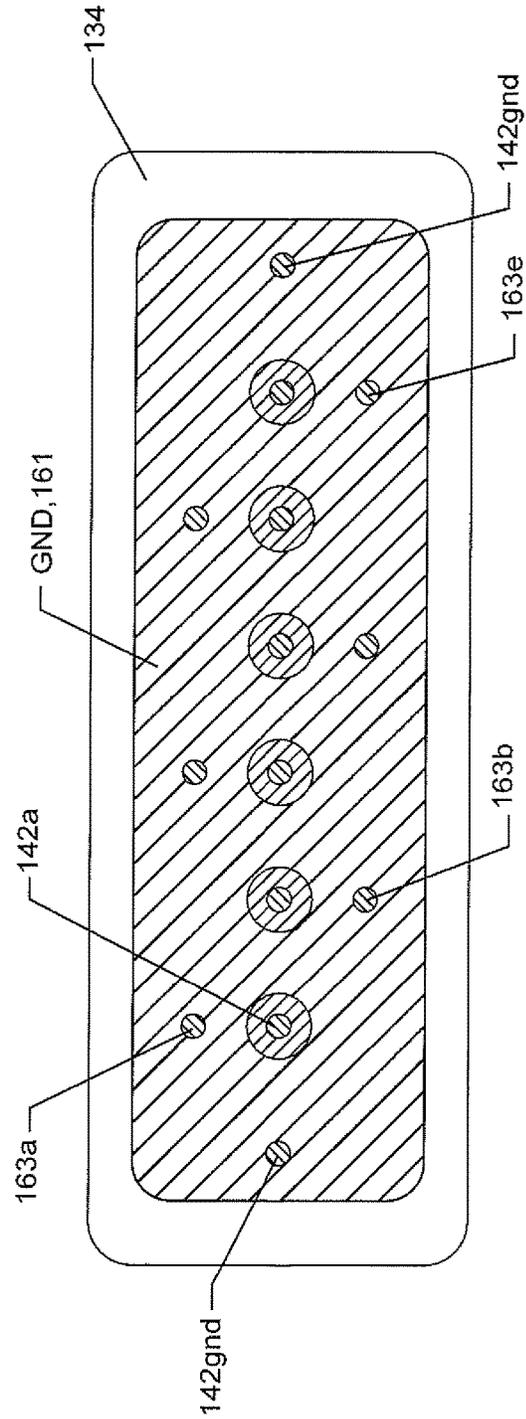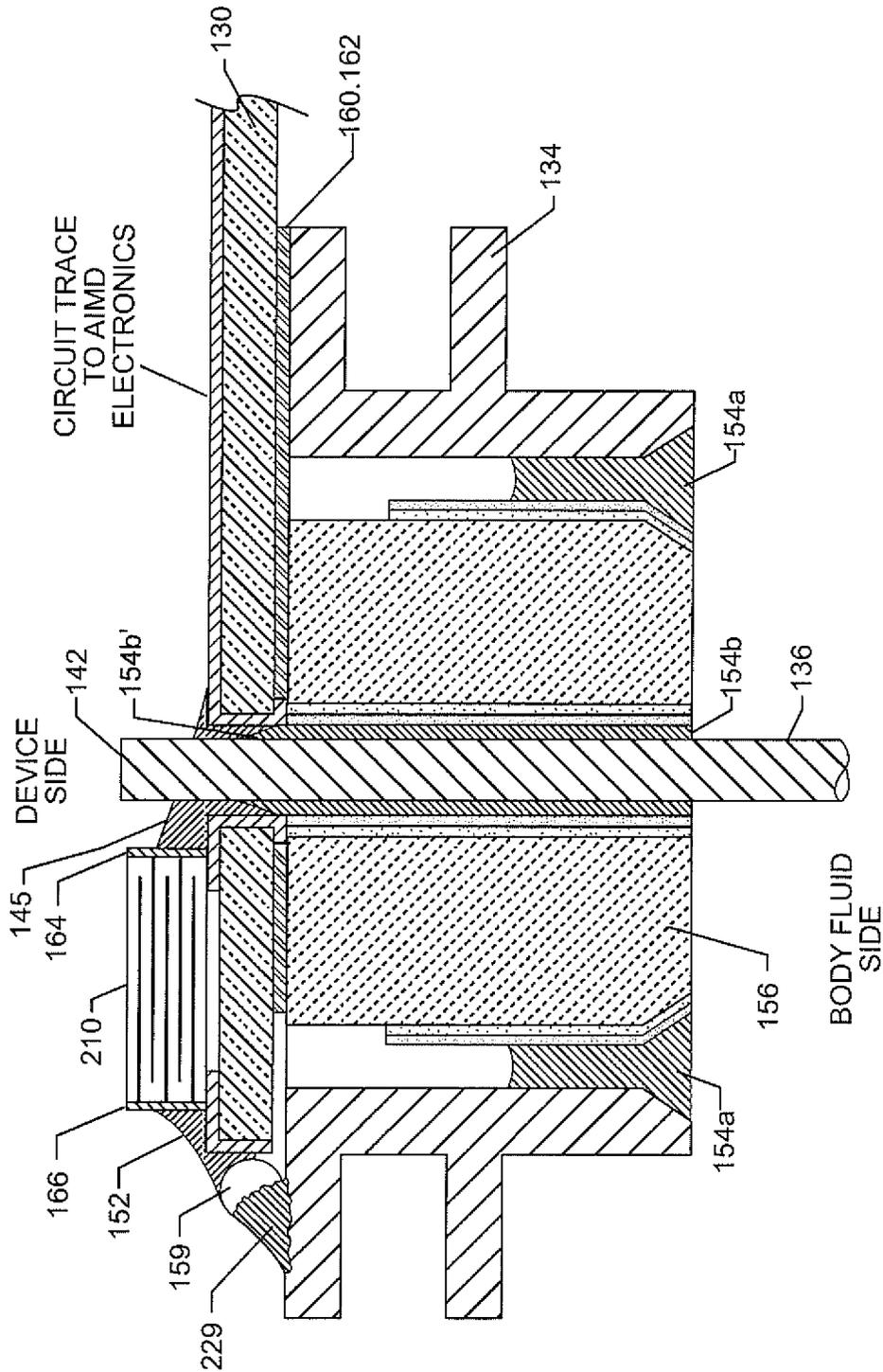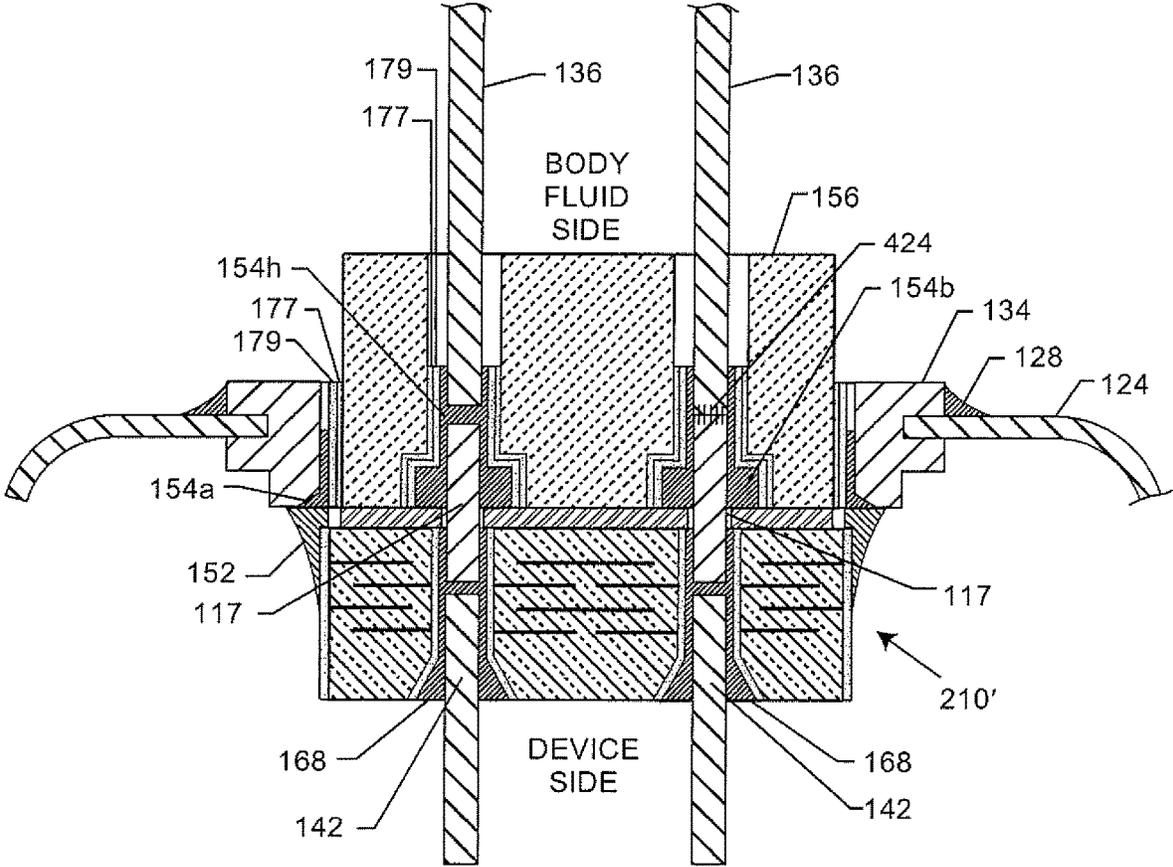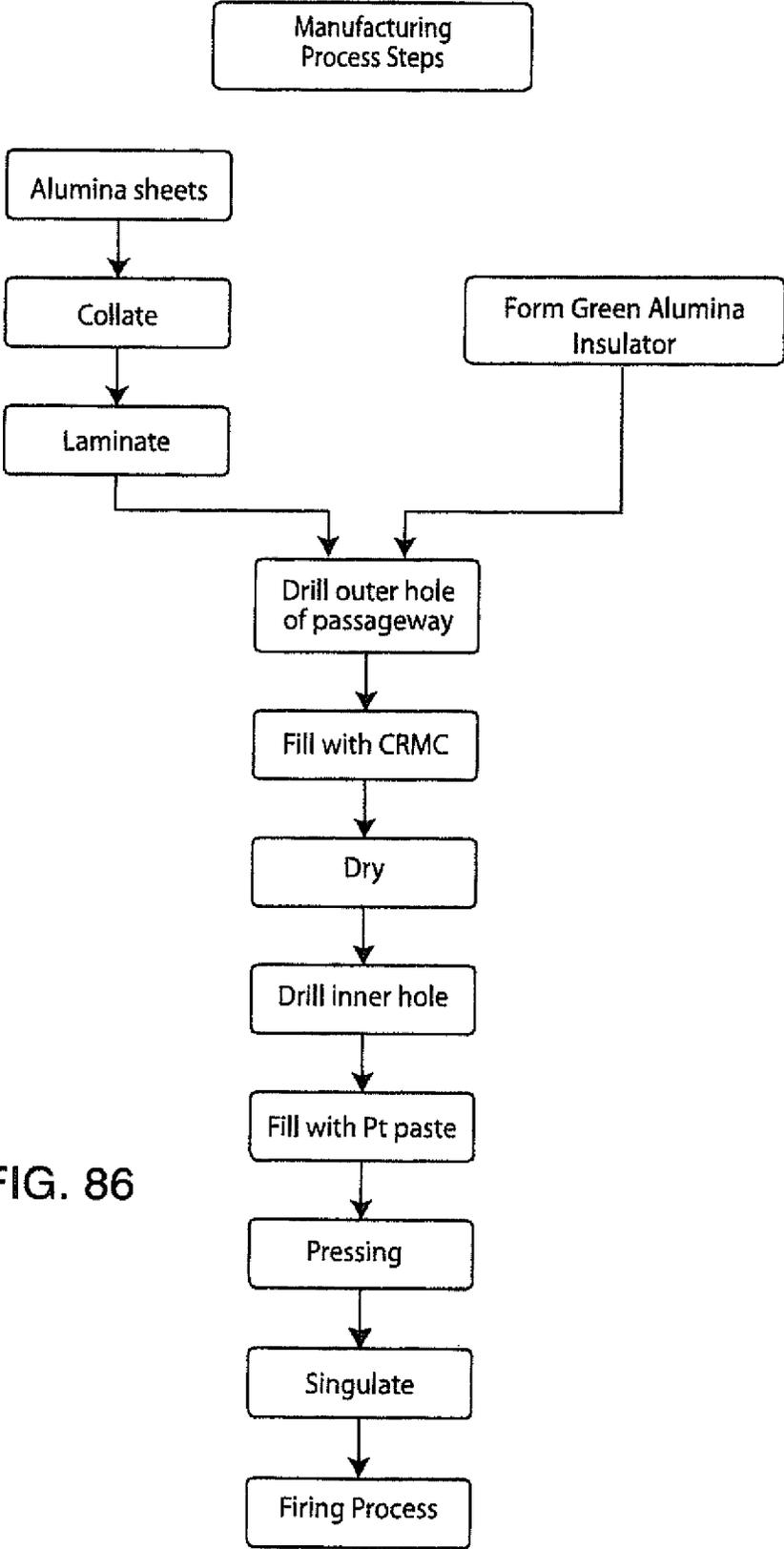
FIG. 86
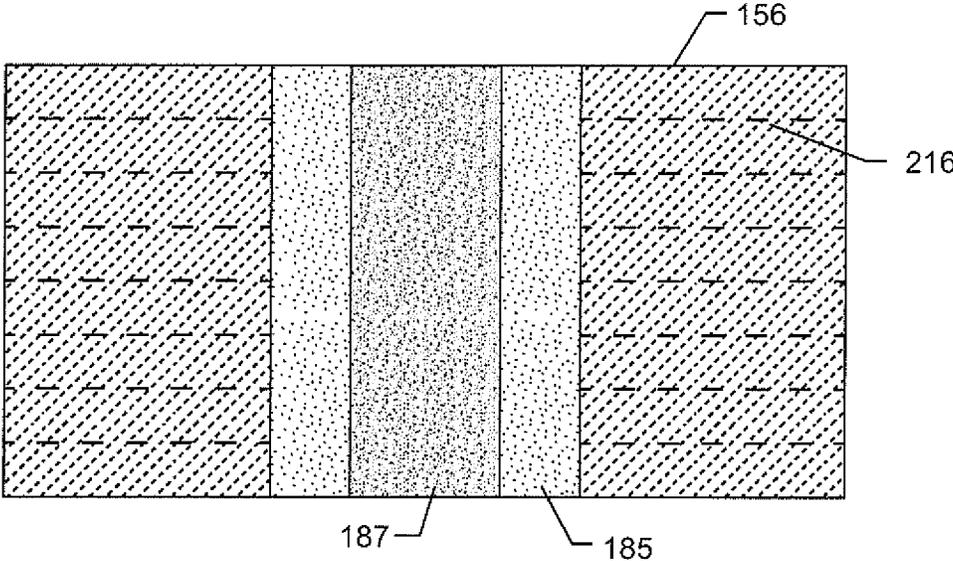
FIG. 87
(BEFORE PRESSING)
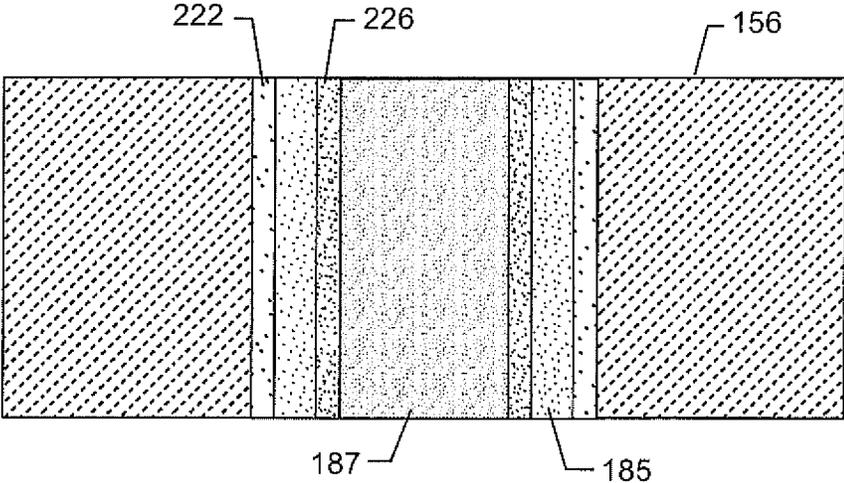
FIG. 88
(AFTER PRESSING)

LOW EQUIVALENT SERIES RESISTANCE RF FILTER CIRCUIT BOARD FOR AN ACTIVE IMPLANTABLE MEDICAL DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a continuation-in-part of U.S. application Ser. No. 16/827,171, filed on Mar. 23, 2020, now U.S. Pat. No. 11,071,858, which is a continuation of U.S. application Ser. No. 16/121,716, filed on Sep. 5, 2018, now U.S. Pat. No. 10,596,369, which is a continuation-in-part to U.S. application Ser. No. 15/943,998, filed on Apr. 3, 2018, now U.S. Pat. No. 10,350,421, which claims priority from U.S. App. Ser. No. 62/646,552, filed on Mar. 22, 2018.

The present application is also a continuation-in-part of U.S. application Ser. No. 15/797,278, filed on Oct. 30, 2017, now U.S. Pat. No. 10,272,253, which is a continuation-in-part of U.S. application Ser. No. 15/704,657, filed on Sep. 14, 2017, now U.S. Pat. No. 10,092,749, which claims priority from U.S. App. Ser. No. 62/552,363, filed on Aug. 30, 2017.

The present application is also a continuation-in-part of U.S. application Ser. No. 15/603,521, filed on May 24, 2017, now U.S. Pat. No. 10,272,252, which claims priority from U.S. App. Ser. Nos. 62/461,872, filed on Feb. 22, 2017; 62/450,187, filed on Jan. 25, 2017; 62/443,011, filed on Jan. 6, 2017; 62/422,064, filed on Nov. 15, 2016; and 62/420, 164, filed on Nov. 10, 2016.

The present application is also a continuation-in-part of U.S. application Ser. No. 15/250,210, filed on Aug. 29, 2016, now U.S. Pat. No. 9,931,514, which is a continuation of U.S. application Ser. No. 15/163,241, filed on May 24, 2016, now U.S. Pat. No. 9,764,129, which is a continuation-in-part to U.S. application Ser. No. 14/826,229, filed on Aug. 14, 2015, now U.S. Pat. No. 9,427,596, which is a continuation of U.S. application Ser. No. 14/688,302, filed on Apr. 16, 2015, now U.S. Pat. No. 9,757,558, which is a continuation-in-part to U.S. application Ser. No. 14/202,653, filed on Mar. 10, 2014, now U.S. Pat. No. 9,014,808, which is a continuation of U.S. application Ser. No. 14/808,849, filed on Nov. 25, 2013, now U.S. Pat. No. 8,855,768, which claims priority from U.S. App. Ser. No. 61/841,419, filed on Jun. 30, 2013.

The present application is also a continuation-in-part of U.S. application Ser. No. 13/408,020, filed on Feb. 29, 2012, abandoned, which claims priority from U.S. App. Ser. No. 61/448,069, filed on Mar. 1, 2011.

The present application is also a continuation-in-part of U.S. application Ser. No. 16/589,752, filed on Oct. 1, 2019, which is a continuation of Ser. No. 16/004,569, filed on Jun. 11, 2018, now U.S. Pat. No. 11,198,014.

The present application also claims priority to U.S. App. Ser. No. 62/979,600 filed on Feb. 21, 2020.

The contents of all the above applications are fully incorporated herein by these references.

FIELD OF THE INVENTION

This invention generally relates to the problem of RF energy induced into implanted leads during medical diagnostic procedures such as magnetic resonant imaging (MRI), and provides methods and apparatus for redirecting RF energy to locations other than the distal tip electrode-to-tissue interface. More specifically, the present invention utilizes either an MLCC chip capacitor, a flat-through filter capacitor or an X2Y attenuator having a dielectric k greater than 0 and less than 1,000 to provide electromagnetic

interference (EMI) protection to sensitive active implantable medical device (AIMD) electronics.

BACKGROUND OF THE INVENTION

Compatibility of cardiac pacemakers, implantable defibrillators and other types of active implantable medical devices with magnetic resonance imaging (MRI) and other types of hospital diagnostic equipment has become a major issue. If one proceeds to the websites of the major cardiac pacemaker manufacturers in the United States, which include St. Jude Medical, Medtronic and Boston Scientific (formerly Guidant), one will see that the use of MRI is generally contra-indicated for patients with implanted pacemakers and cardioverter defibrillators. See also recent press announcements of the Medtronic Revo MRI pacemaker which was recently approved by the U.S. FDA. With certain technical limitations as to scan type and location, this is the first pacemaker designed for MRI scanning. See also:

(1) "Safety Aspects of Cardiac Pacemakers in Magnetic Resonance Imaging", a dissertation submitted to the Swiss Federal Institute of Technology Zurich presented by Roger Christoph Luchinger, Zurich 2002;

(2) "1. Dielectric Properties of Biological Tissues: Literature Survey", by C. Gabriel, S. Gabriel and E. Cortout;

(3) "II. Dielectric Properties of Biological Tissues: Measurements and the Frequency Range 0 Hz to 20 GHz", by S. Gabriel, R. W. Lau and C. Gabriel;

(4) "III. Dielectric Properties of Biological Tissues: Parametric Models for the Dielectric Spectrum of Tissues", by S. Gabriel, R. W. Lau and C. Gabriel;

(5) "Advanced Engineering Electromagnetics", C. A. Balanis, Wiley, 1989; (6) Systems and Methods for Magnetic-Resonance-Guided Interventional Procedures, U.S. Pat. No. 7,844,319, Susil and Halperin et al., filed Apr. 15, 2002;

(7) Multifunctional Interventional Devices for MRI: A Combined Electrophysiology/MRI Catheter, by, Robert C. Susil, Henry R. Halperin, Christopher J. Yeung, Albert C. Lardo and Ergin Atalar, MRI in Medicine, 2002; and

(8) Multifunctional Interventional Devices for Use in MRI, U.S. Pat. No. 7,844,534, Susil et al., issued Nov. 30, 2010.

The contents of the foregoing are all incorporated herein by these references.

However, an extensive review of the literature indicates that, despite being contra-indicated, MRI is indeed often used to image patients with pacemaker, neurostimulator and other active implantable medical devices (AIMDs). As such, the safety and feasibility of MRI in patients with cardiac pacemakers is an issue of gaining significance. The effects of MRI on patients' pacemaker systems have only been analyzed retrospectively in some case reports. There are a number of papers that indicate that MRI on new generation pacemakers can be conducted up to 0.5 Tesla (T). MRI is one of medicine's most valuable diagnostic tools. MRI is, of course, extensively used for imaging, but is also used for interventional medicine (surgery). In addition, MRI is used in real time to guide ablation catheters, neurostimulator tips, deep brain probes and the like. An absolute contra-indication for pacemaker or neurostimulator patients means that these patients are excluded from MRI. This is particularly true of scans of the thorax and abdominal areas. Because of MRI's incredible value as a diagnostic tool for imaging organs and other body tissues, many physicians simply take the risk and go ahead and perform MRI on a pacemaker patient. The literature indicates a number of precautions that physicians should take in this case, including limiting the power of the

MRI RF-pulse field (Specific Absorption Rate—SAR level), programming the pacemaker to fixed or asynchronous pacing mode, and then careful reprogramming and evaluation of the pacemaker and patient after the procedure is complete. There have been reports of latent problems with cardiac pacemakers or other AIMDs after an MRI procedure sometimes occurring many days later. Moreover, there are a number of recent papers that indicate that the SAR level is not entirely predictive of the heating that can be found in implanted leads or devices. For example, for magnetic resonance imaging devices operating at the same magnetic field strength and also at the same SAR level, considerable variations have been found relative to heating of implanted leads. It is speculated that SAR level alone is not a good predictor of whether or not an implanted device or its associated lead system will overheat.

There are three types of electromagnetic fields used in an MRI unit. The first type is the main static magnetic field designated B_0 which is used to align protons in body tissue. The field strength varies from 0.5 to 3.0 Tesla in most of the currently available MRI units in clinical use. Some of the newer MRI system fields can go as high as 4 to 5 Tesla. At the International Society for Magnetic Resonance in Medicine (ISMRM), which was held on 5-6 Nov. 2005, it was reported that certain research systems are going up as high as 11.7 Tesla. This is over 100,000 times the magnetic field strength of the earth. A static magnetic field can induce powerful mechanical forces and torque on any magnetic materials implanted within the patient. This includes certain components within the cardiac pacemaker itself and/or lead systems. It is not likely (other than sudden system shut down) that the static MRI magnetic field can induce currents into the pacemaker lead system and hence into the pacemaker itself. It is a basic principle of physics that a magnetic field must either be time-varying as it cuts across the conductor, or the conductor itself must move within a specifically varying magnetic field for currents to be induced.

The second type of field produced by magnetic resonance imaging is the RF-pulse field which is generated by a body coil or a head coil. This is used to change the energy state of the protons and elicit MRI signals from tissue. The RF field is homogeneous in the central region and has two main components: (1) the electric field is circularly polarized in the actual plane; and (2) the H field, sometimes generally referred to as the net magnetic field in matter, is related to the electric field by Maxwell's equations and is relatively uniform. In general, the RF field is switched on and off during measurements and usually has a frequency of about 21 MHz to about 500 MHz depending upon the static magnetic field strength. The frequency of the RF pulse for hydrogen scans varies by the Lamour equation with the field strength of the main static field where: RF-PULSE FREQUENCY in MHz=(42.56) (STATIC FIELD STRENGTH IN TESLA). There are also phosphorous and other types of scanners wherein the Lamour equation would be different. The present invention applies to all such scanners.

The third type of electromagnetic field is the time-varying magnetic gradient fields designated B_X, B_Y, B_Z, which are used for spatial localization. These change their strength along different orientations and operating frequencies on the order of 2-5 kHz. The vectors of the magnetic field gradients in the X, Y and Z directions are produced by three sets of orthogonally positioned coils and are switched on only during the measurements. In some cases, the gradient field has been shown to elevate natural heart rhythms (heart beat). This is not completely understood, but it is a repeatable

phenomenon. The gradient field is not considered by many researchers to create any other adverse effects.

It is instructive to note how voltages and electro-magnetic interference (EMI) are induced into an implanted lead system. At very low frequency (VLF), voltages are induced at the input to the cardiac pacemaker as currents circulate throughout the patient's body and create voltage drops. Because of the vector displacement between the pacemaker housing and, for example, the tip electrode, voltage drop across the resistance of body tissues may be sensed due to Ohms Law and the circulating current of the RF signal. At higher frequencies, the implanted lead systems actually act as antennas wherein voltages (EMFs) are induced along their length. These antennas are not very efficient due to the damping effects of body tissue; however, this can often be offset by extremely high-power fields (such as MRI pulse fields) and/or body resonances. At very high frequencies (such as cellular telephone frequencies), EMI signals are induced only into the first area of the leadwire system (for example, at the header block of a cardiac pacemaker). This has to do with the wavelength of the signals involved wherein the signals couple efficiently into the system.

Magnetic field coupling into an implanted lead system is based on loop areas. For example, in a cardiac pacemaker unipolar lead, there is a loop formed by the lead as it comes from the cardiac pacemaker housing to its distal tip electrode, for example, located in the right ventricle. The return path is through body fluid and tissue generally straight from the tip electrode in the right ventricle back up to the pacemaker case or housing. This forms an enclosed area which can be measured from patient X-rays in square centimeters. The average loop area is 200 to 225 square centimeters. This is an average and is subject to great statistical variation. For example, in a large adult patient with an abdominal pacemaker implant, the implanted loop area is much larger (around 400 square centimeters).

Relating now to the specific case of MRI, the magnetic gradient fields are induced through enclosed loop areas. However, the RF-pulse fields generated by the body coil are primarily induced into the lead system by antenna action. Subjected to RF frequencies, the lead itself can exhibit complex transmission line behavior.

At the frequencies of interest in MRI, RF energy can be absorbed and converted to heat. The power deposited by RF pulses during MRI is complex and is dependent upon the power [Specific Absorption Rate (SAR) Level] and duration of the RF pulse, the transmitted frequency, the number of RF pulses applied per unit time, and the type of configuration of the RF transmitter coil used. The amount of heating also depends upon the volume of tissue imaged, the electrical resistivity of tissue and the configuration of the anatomical region imaged. There are also a number of other variables that depend on the placement in the human body of the AIMD and the length and trajectory of its associated lead(s). For example, it will make a difference how much EMF is induced into a pacemaker lead system as to whether it is a left or right pectoral implant. In addition, the routing of the lead and the lead length are also very critical as to the amount of induced current and heating that can occur. Also, distal tip design is very important as it can heat up due to MRI RF induced energy.

The cause of heating in an MRI environment is twofold: (a) RF field coupling to the lead can occur which induces significant local heating; and (b) currents induced between the distal tip and tissue during MRI RF pulse transmission sequences can cause local Ohms Law (resistive) heating in tissue next to the distal tip electrode of the implanted lead.

The RF field of an MRI scanner can produce enough energy to induce RF voltages in an implanted lead and resulting currents sufficient to damage some of the adjacent myocardial tissue. Tissue ablation (destruction resulting in scars) has also been observed. The effects of this heating are not readily detectable by monitoring during the MRI. Indications that heating has occurred includes an increase in pacing threshold, venous ablation, larynx or esophageal ablation, myocardial perforation and lead penetration, or even arrhythmias caused by scar tissue. Such long-term heating effects of MRI have not been well studied yet for all types of AIMD lead geometries. There can also be localized heating problems associated with various types of electrodes in addition to tip electrodes. This includes ring electrodes or pad electrodes. Ring electrodes are commonly used with a wide variety of implanted devices including cardiac pacemakers, and neurostimulators, and the like. Pad electrodes are very common in neurostimulator applications. For example, spinal cord stimulators or deep brain stimulators can include at least ten pad electrodes to make contact with nerve tissue. A good example of this also occurs in a cochlear implant. In a typical cochlear implant there are sixteen pad electrodes placed up into the cochlea. Several of these pad electrodes make contact with auditory nerves.

Although there are a number of studies that have shown that MRI patients with active implantable medical devices, such as cardiac pacemakers, can be at risk for potential hazardous effects, there are a number of reports in the literature that MRI can be safe for imaging of pacemaker patients when a number of precautions are taken (only when an MRI is thought to be an absolute diagnostic necessity). While these anecdotal reports are of interest, they are certainly not scientifically convincing that all MRI can be safe. For example, just variations in the pacemaker lead length and implant trajectory can significantly affect how much heat is generated. A paper entitled, HEATING AROUND INTRAVASCULAR GUIDEWIRES BY RESONATING RF WAVES by Konings, et al., journal of Magnetic Resonance Imaging, Issue 12:79-85 (2000), does an excellent job of explaining how the RF fields from MRI scanners can couple into implanted leads. The paper includes both a theoretical approach and actual temperature measurements. In a worst-case, they measured temperature rises of up to 74 degrees C. after 30 seconds of scanning exposure. The content of this paper is fully incorporated herein by this reference.

The effect of an MRI system on the function of pacemakers, ICDs, neurostimulators and the like, depends on various factors, including the strength of the static magnetic field, the pulse sequence, the strength of RF field, the anatomic region being imaged, and many other factors. Further complicating this is the fact that each patient's condition and physiology is different, and each lead implant has a different length and/or implant trajectory in body tissues. Most experts still conclude that MRI for the pacemaker patient should not be considered safe.

It is well known that many of the undesirable effects in an implanted lead system from MRI and other medical diagnostic procedures are related to undesirable induced EMFs in the lead system and/or RF currents in its distal tip (or ring) electrodes. This can lead to overheating of body tissue at or adjacent to the distal tip.

Distal tip electrodes can be unipolar, bipolar and the like. It is very important that excessive current not flow at the interface between the lead distal tip electrode and body tissue. In a typical cardiac pacemaker, for example, the distal tip electrode can be passive or of a screw-in helix type as

will be more fully described. In any event, it is very important that excessive RF current not flow at this junction between the distal tip electrode and for example, myocardial or nerve tissue. Excessive current at the distal electrode to tissue interface can cause excessive heating of said tissue to the point of tissue ablation or even tissue perforation, which can be life threatening for cardiac patients. For neurostimulator patients, such as deep brain stimulator patients, thermal injury can cause coma, permanent disability or can even be life-threatening. Similar issues exist for spinal cord stimulator patients, cochlear implant patients and the like.

Interestingly, the inventors performed an experiment in an MRI scanner with a human body gel-filled phantom. In the phantom, placed in an anatomic position, was an operating pacemaker and a lead. This was during evaluation of the efficacy of bandstop filters at or near the distal tip electrode for preventing the distal tip electrode from overheating. Bandstop filters for this purpose are more thoroughly described in U.S. Pat. No. 7,363,090, the content of which is fully incorporated herein by this reference. During the experiments, there was a control lead that had no bandstop filter. During a particularly RF intense scanning sequence, Luxtron probes measured a distal helix tip electrode temperature rise of 30° C. Of course, the 30° C. temperature rise in a patient would be very alarming as it can lead to pacing capture threshold changes or even complete loss capture due to scar tissue formation. An identical lead with the bandstop filter in place only had a temperature rise of 3° C. This was a remarkable validation of the efficacy of bandstop filters for implantable electrodes. However, something very interesting happened when we disconnected the pacemaker. We disconnected the pacemaker and put a silicone lead cap over the proximal end of the lead. Again, we put the gel phantom back inside the MR scanner and this time we measured an 11° C. temperature rise on the lead with the bandstop filter. This was proof positive that the housing of the AIMD acts as part of the system. The prior art feedthrough capacitor created a fairly low impedance at the input to the pacemaker and thereby drew RF energy out of the lead and diverted it to the housing of the pacemaker. It has recently been discovered that the impedance, and in particular, the ESR of these capacitors, is very important so that maximal energy can be pulled from the lead and diverted to the pacemaker housing while at the same time, not unduly overheating the feedthrough capacitor.

Accordingly, there is a need for novel low ESR diverting capacitors and circuits which are frequency selective and are constructed of passive components for implantable leads and/or leadwires. Further, there is a need for very low ESR diverter element capacitor(s) which are designed to decouple a maximum amount of induced RF energy from an implanted lead to an AIMD housing while at the same time not overheat. The present invention fulfills these needs and provides other related advantages.

SUMMARY OF THE INVENTION

An exemplary embodiment of the present invention is a filtered feedthrough assembly attachable to an opening of a housing of an active implantable medical device. The filtered feedthrough assembly comprises: a hermetic feedthrough comprising: (I) a metallic and electrically conductive ferrule configured to be installed in the opening of the housing of the active implantable medical device, the ferrule separating a body fluid side opposite a device side, and the ferrule comprising a ferrule opening extending from the body fluid side to the device side; (ii) an insulator disposed

at least partially within the ferrule opening; (iii) a first hermetic seal disposed between the insulator and the ferrule opening hermetically sealing the insulator to the ferrule; (iv) at least one passageway disposed through the insulator extending from the body fluid side to the device side; (v) a conductive pathway disposed within the at least one passageway, the conductive pathway hermetically sealed to the at least one passageway. At least one filter capacitor is disposed on the device side, comprising: (i) at least one active electrode plate and at least one ground electrode plate disposed within a capacitor dielectric body in spaced and interleaved relation with each other; (ii) a capacitor active metallization attached to the capacitor dielectric body and electrically connected to the at least one active electrode plate; (iii) a ground capacitor metallization attached to the capacitor dielectric body and electrically connected to the at least one ground electrode plate; (iv) wherein the at least one filter capacitor is the first filter capacitor electrically connected to the conductive pathway coming from the body fluid side into the device side; (v) wherein the capacitor dielectric body (148) has a dielectric constant k that is greater than 0 and less than 1,000. An active electrical connection electrically connects the conductive pathway to the capacitor active metallization, and a ground electrical connection electrically connects the ground capacitor metallization to the ferrule. Further embodiments of the invention are now discussed herein.

As best shown in FIGS. 63-64C and 65A-65R, the at least one filter capacitor may be a flat-through filter capacitor.

Furthermore, the flat-through filter capacitor may be disposed at least partially over the insulator in a tombstone mounting position, wherein the at least one active electrode plate and the at least one ground electrode plate are disposed perpendicular in relation to an outside surface of the ferrule on the device side, best shown in FIGS. 65A-65R.

The ground capacitor metallization may be disposed at an edge of the flat-through filter capacitor as shown in FIG. 65A. The ground electrical connection may comprise a conductive wire gold brazed or welded to the ferrule. The ground electrical connection may comprise a conductive material electrically connecting the ground capacitor metallization to the conductive wire gold brazed or welded to the ferrule. The ground electrical connection may comprise a gold pocket-pad disposed within a pocket formed in the outside surface of the ferrule. The ground electrical connection may comprise a conductive material electrically connecting the ground capacitor metallization to the gold pocket-pad. The ground electrical connection may comprise a conductive material electrically connecting the ground capacitor metallization to a gold braze forming the first hermetic seal. The ground electrical connection may comprise a metallization layer disposed on the outside surface of the ferrule which is overlaid by an electrically conductive adhesive. The ground electrical connection may comprise a conductive material electrically connecting the ground capacitor metallization to the electrically conductive adhesive.

The ground capacitor metallization may be disposed in a middle of the flat-through filter capacitor as best shown in FIG. 65E. The ground electrical connection may comprise a conductive wire gold brazed or welded to a peninsula or a bridge extending into the ferrule opening of the ferrule. The ground electrical connection may comprise a conductive material electrically connecting the ground capacitor metallization to the conductive wire gold brazed or welded to the ferrule. The ground electrical connection may comprise a gold pocket-pad disposed within a pocket formed in the

outside surface of a peninsula or a bridge extending into the ferrule opening of the ferrule. The ground electrical connection may comprise a conductive material electrically connecting the ground capacitor metallization to the gold pocket-pad.

As best shown in FIG. 65I, the ground capacitor metallization may comprise a first ground capacitor metallization disposed at an edge of the flat-through filter capacitor and a second ground capacitor metallization disposed in a middle of the flat-through capacitor, wherein the second ground metallization is electrically connected to the ferrule at a peninsula or a bridge extending into the ferrule opening of the ferrule.

The flat-through filter capacitor may be disposed on a circuit board, the circuit board comprising at least one ground plate disposed in or on the circuit board, and wherein the at least one ground plate is electrically connected to the ground capacitor metallization and to the ferrule.

The at least one filter capacitor may be an X2Y attenuator filter capacitor.

As best shown in FIGS. 70C and 70D, the at least one filter capacitor may be disposed at least partially over the insulator in a tombstone mounting position, wherein the at least one active electrode plate and the at least one ground electrode plate are disposed perpendicular in relation to an outside surface of the ferrule on the device side. The ground electrical connection may comprise a conductive material electrically connecting the ground capacitor metallization to a gold braze forming the first hermetic seal.

The X2Y attenuator filter capacitor may be disposed on a circuit board, the circuit board comprising at least one ground plate disposed in or on the circuit board, and wherein the at least one ground plate is electrically connected to the ground capacitor metallization and to the ferrule.

The first hermetic seal may comprise a first gold braze. The conductive pathway may comprise a leadwire, the leadwire hermetically sealing the at least one passageway by a second gold braze.

The conductive pathway may comprise a platinum fill co-fired with the insulator or the conductive pathway may comprise a ceramic reinforced metal composite co-fired with the insulator.

As best shown in FIGS. 70C and 70D, another embodiment of the present invention is a filtered feedthrough assembly attachable to an opening of a housing of an active implantable medical device, the filtered feedthrough assembly comprising: a) a hermetic feedthrough, comprising: (i) a metallic and electrically conductive ferrule configured to be installed in the opening of the housing of the active implantable medical device, the ferrule separating a body fluid side opposite a device side, and the ferrule comprising a ferrule opening extending from the body fluid side to the device side; (ii) an insulator disposed at least partially within the ferrule opening; (iii) a first hermetic seal disposed between the insulator and the ferrule opening hermetically sealing the insulator to the ferrule; (iv) a first and a second passageway disposed through the insulator extending from the body fluid side to the device side; (v) a first and a second conductive pathway disposed respectively within the first and the second passageway, the conductive pathways hermetically sealed to their respective passageways; b) an X2Y attenuator filter capacitor disposed on the device side, comprising: (i) at least a first and a second active electrode plate and at least one ground electrode plate (146) disposed within a capacitor dielectric body in spaced and interleaved relation with each other; (ii) a first and a second capacitor active metallization attached to the capacitor dielectric body and electrically

connected respectively to the first and the second active electrode plates; (iii) a ground capacitor metallization attached to the capacitor dielectric body and electrically connected to the at least one ground electrode plate; (iv) wherein the X2Y attenuator filter capacitor is the first filter capacitor electrically connected to the conductive pathways coming from the body fluid side into the device side; (v) wherein the X2Y attenuator filter capacitor is disposed at least partially over the insulator in a tombstone mounting position, wherein the at least the first and the second active electrode plate and the at least one ground electrode plate are disposed perpendicular in relation to an outside surface of the ferrule on the device side; c) a first active electrical connection electrically connecting the first conductive pathway to the first capacitor active metallization; d) a second active electrical connection electrically connecting the second conductive pathway to the second capacitor active metallization; and e) a ground electrical connection electrically connecting the ground capacitor metallization to the ferrule.

Other features and advantages of the present invention will become apparent from the following more detailed description, taken in conjunction with the accompanying drawings which illustrate, by way of example, the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings illustrate the invention. In such drawings:

FIG. 1 is a wire-formed diagram of a generic human body showing a number of exemplary implanted medical devices;

FIG. 2 is a pictorial view of an AIMD patient who is about to be placed into an MRI scanner;

FIG. 3 shows a side view of the patient within the scanner showing an intense RF field impinging on the implanted medical device and its associated lead;

FIG. 4 is a top view of the patient in the MRI scanner showing one location of the AIMD and its associated lead;

FIG. 5 is a line drawing of a human heart with cardiac pacemaker dual chamber bipolar leads shown in the right ventricle and the right atrium;

FIG. 6 illustrates a dual chamber cardiac pacemaker with its associated leads and electrodes implanted into a human heart;

FIG. 7 is an isometric view illustrating the rectangular feedthrough capacitor mounted to a hermetic terminal;

FIG. 8 is an enlarged cross-sectional view taken generally along the line 8-8 of FIG. 7;

FIG. 9 is an isometric view of a round hermetic terminal showing a quad polar RF diverter feedthrough capacitor;

FIG. 10 is an enlarged cross-sectional view taken generally along the line 10-10 from FIG. 9;

FIG. 11 is an electrical schematic diagram of the quad polar feedthrough capacitor of FIGS. 7-10;

FIG. 12 is a cross-sectional view of an embodiment of a hermetic terminal subassembly installed in a housing of an AIMD;

FIG. 13 is a cross-sectional view of another embodiment of a hermetic terminal subassembly now showing a capacitor with a filled and a bore-coated via;

FIG. 14 is an isometric view of a monolithic multi-layer ceramic capacitor (MLCC) chip capacitor;

FIG. 15 is a cross-sectional view of the monolithic ceramic capacitor, taken along the line 15-15 of FIG. 14;

FIG. 16 is an electrical schematic diagram of an ideal MLCC chip capacitor as illustrated in FIGS. 14 and 15;

FIG. 17 is an isometric view of a flat-through three-terminal capacitor;

FIG. 18 illustrates the internal electrode plates of the flat-through capacitor of FIG. 17;

FIG. 18A is the electrical schematic of FIGS. 17 and 18;

FIG. 19 is an isometric exploded view of a multi-lead hermetic feedthrough with substrate mounted MLCC chip capacitors showing use of a substrate between the feedthrough and the filter support assembly;

FIG. 19A is the electrical schematic of FIG. 19;

FIG. 20 illustrates a cross-sectional view of an MLCC chip capacitor mounted to separate circuit traces;

FIG. 21 is a schematic representation explaining the elements that are components of the FIG. 20 capacitor's equivalent series resistance (ESR);

FIG. 22 is an equation that relates the capacitance with the capacitor's active area, dielectric constant, number of electrode plates and dielectric thickness;

FIG. 23 shows the difference between an ideal capacitor and a real capacitor, including dielectric loss tangent and dissipation factor;

FIG. 24 gives the formulas for capacitive reactance, dissipation factor, equivalent series resistance (ESR) and dielectric loss tangent;

FIG. 25 is an equivalent circuit model for a real capacitor;

FIG. 26 is a schematic illustrating a simplified model for capacitor ESR;

FIG. 27 is a graph illustrating capacitor dielectric loss versus frequency;

FIG. 28 is a graph illustrating normalized curves which show the capacitor equivalent series resistance (ESR) on the y axis, versus frequency on the x axis;

FIG. 29 illustrates the reactance and real losses of a 2,000-picofarad X7R feedthrough capacitor;

FIG. 30 illustrates the reactance and real losses of a 2,000-picofarad C0G (NP0) capacitor;

FIG. 31 is a graph illustrating capacitor equivalent series resistance versus frequency as illustrated in a sweep from an Agilent E4991A materials analyzer;

FIG. 32 is a cross-sectional view of a low k MLCC chip capacitor with an increased number of electrode plates to minimize ESR;

FIG. 33 is an equation showing that the total high frequency electrode resistive losses drop in accordance with the parallel plate formula for capacitor electrode plates;

FIG. 34 is a cross-sectional view of a quad polar feedthrough capacitor similar to FIGS. 9 and 10 except that it is low ESR and designed for maximal heat flow;

FIG. 35 is a partial cross-section taken from section 35-35 from FIG. 34 illustrating dual electrode plates to minimize capacitor ESR and maximize heat flow out of the capacitor;

FIG. 36 is similar to FIG. 35 except that just the ground electrode plates have been doubled;

FIG. 37 illustrates a family of lowpass filters indicating the present invention can be anything from a simple diverter capacitor 140 to an n-element lowpass filter;

FIG. 38 illustrates a feedthrough diverter capacitor, a bandstop filter and an L-C trap;

FIG. 39 illustrates a cardiac pacemaker with a diverter feedthrough capacitor and also a circuit board mounted chip capacitor filter which forms a composite filter and also spreads out heat generation;

FIG. 39A illustrates the electrical schematic of FIG. 39;

FIG. 39B is a perspective view showing the capacitor mounted to a flexible connection;

FIG. 39C illustrates the electrical schematic of FIG. 39B;

FIG. 40 is a fragmented perspective view of an EMI shield conduit mounted to a circuit board having multiple MLCC chip capacitors;

FIG. 41 is a cross-sectional view of a flex cable embodying the present invention;

FIG. 42 is a sectional view taken along line 42-42 of FIG. 41;

FIG. 43 is a sectional view taken along the line 43-43 of FIG. 41, illustrating an alternative to the internal circuit traces disclosed with respect to FIG. 42;

FIG. 44 is a sectional view taken along line 44-44 of FIG. 41, illustrating one of a pair of coaxially surrounding shields disposed about the circuit trace;

FIG. 45 is an isometric view of the flex cable of FIG. 41 connected to a circuit board or substrate having a flat-through capacitor;

FIG. 46 is the top view of the flat-through capacitor from FIG. 45;

FIG. 47 illustrates the active electrode plates of the flat-through capacitor of FIGS. 45 and 46;

FIG. 48 illustrates the ground electrode plate of the flat-through capacitor of FIGS. 45 and 46;

FIG. 49 illustrates a family of lowpass filters, which is very similar to the family of lowpass filters described in FIG. 37;

FIG. 49A is similar to FIG. 49 now showing the attenuation curve for a feedthrough capacitor with chip capacitor;

FIG. 50 illustrates that the high energy dissipating low ESR capacitor can be used in combination with other circuits;

FIG. 51 shows an isometric view of an MLCC chip capacitor that is similar in its exterior appearance to the prior art MLCC chip capacitor previously described in FIGS. 14 and 15;

FIG. 52 is a cross-sectional view taken along lines 52-52 of FIG. 51;

FIG. 53 is the electrical schematic representation of FIGS. 51 and 52;

FIG. 54 is an isometric view of a bipolar hermetic seal having a ferrule and two leads passing through the conductive ferrule in insulative relationship;

FIG. 55 is the electrical schematic representation of FIG. 54;

FIG. 56 is similar to FIG. 6 showing a breakaway cross-section of a typical AIMD with novel capacitors mounted to an internally disposed circuit board;

FIG. 56A is the electrical schematic of FIG. 56;

FIG. 57 is very similar to FIG. 56 except that a diode array has been added;

FIG. 58 is the electrical schematic representation of FIG. 57;

FIG. 59 is very similar to FIG. 58 except the high voltage protection diode array is shown on the other side of the low ESR capacitors;

FIG. 60 is an electrical schematic of a back-to-back diode placed in series taken from lines 60-60 of FIG. 59;

FIG. 61 is very similar to FIG. 56 except that the RF grounding strap has been replaced with a simple leadwire connection;

FIG. 62 is very similar to FIG. 61 now with the grounding leadwire routed directly to the ferrule of the hermetic terminal subassembly;

FIG. 63 is very similar to prior art FIG. 17 that illustrated a flat-through type of feedthrough capacitor;

FIG. 64 is very similar to prior art FIG. 18 that illustrated the electrode plates of the flat-through type of feedthrough capacitor;

FIG. 64A is the electrical schematic for FIGS. 63 and 64;

FIG. 64B is a top view of an embodiment of the flat-through capacitor of FIG. 63 now mounted upon a circuit board;

FIG. 64C is a cross-sectional view taken along lines 64C-64C from the structure of FIG. 64B;

FIG. 64D is an isometric view of a quad polar flat-through filter capacitor;

FIG. 64E is a sectional view taken along lines 64E-64E from the structure of FIG. 64D;

FIG. 64F is the electrical schematic for FIGS. 64D and 64E;

FIG. 65A is a top view of an embodiment of the quad polar flat-through filter capacitor of FIG. 64D now mounted above a ferrule and insulator in a tombstone mounting position;

FIG. 65B is a cross-sectional view taken along lines 65B-65B from the structure of FIG. 65A;

FIG. 65C is an isometric view of an internally grounded quad polar flat-through capacitor;

FIG. 65D is a sectional view taken along lines 65D-65D from the structure of FIG. 65C;

FIG. 65E is a top of view of an embodiment of the internally grounded quad polar flat-through capacitor of FIG. 65C now mounted above a ferrule and insulator in a tombstone mounting position;

FIG. 65F is a cross-sectional view taken along lines 65F-65F from the structure of FIG. 65E;

FIG. 65G is an isometric view of a hybrid quad polar flat-through capacitor;

FIG. 65H is a sectional view taken along lines 65H-65H from the structure of FIG. 65G;

FIG. 65I is a top view of an embodiment of the hybrid quad polar flat-through capacitor of FIG. 65G now mounted above a ferrule and insulator in a tombstone mounting position;

FIG. 65J is a cross-sectional view taken along lines 65J-65J from the structure of FIG. 65I;

FIG. 65Ja is an enlarged partial cross-sectional view generally taken from section 65Ja-65Ja from FIG. 65J now showing a new embodiment of a grounding structure;

FIG. 65Jb is an enlarged partial cross-sectional view generally taken from section 65Jb-65Jb from FIG. 65J now showing a new embodiment of a grounding structure;

FIG. 65Jc is an enlarged partial cross-sectional view generally taken from section 65Jc-65Jc from FIG. 65J now showing a new embodiment of a grounding structure;

FIG. 65Jd is an enlarged partial cross-sectional view generally taken from section 65Jd-65Jd from FIG. 65J now showing a new embodiment of a grounding structure;

FIG. 65K is a top view of an embodiment of the hybrid quad polar flat-through capacitor of FIG. 65G now mounted above a ferrule and insulator in a tombstone mounting position;

FIG. 65L is a side view taken along lines 65L-65L from the structure of FIG. 65K;

FIG. 65M is a side view taken along lines 65M-65M from the structure of FIG. 65K;

FIG. 65N is a top view of another embodiment of a ferrule and insulator structure;

FIG. 65O is an isometric view of a novel flat-through capacitor of the present invention;

FIG. 65P is a view similar to that of FIG. 65O now with the dielectric and outside metallizations removed;

FIG. 65Q is a top view of an embodiment of a flat-through capacitor of FIG. 65O now mounted above a ferrule and insulator in a tombstone mounting position;

FIG. **65R** is a cross-sectional view taken along lines **65R-65R** from the structure of FIG. **65Q**;

FIG. **65S** is a cross-sectional view taken along lines **65S-65S** from the structure of FIG. **65Q**;

FIG. **65T** is a cross-sectional view taken along lines **65T-65T** from the structure of FIG. **65Q**;

FIG. **66** is an isometric view of a bipolar X2Y attenuator;

FIG. **67** shows the internal active electrode plates of FIG. **66** now with the dielectric removed;

FIG. **68** shows the internal ground electrode plates of FIG. **66** now with the dielectric removed;

FIG. **69** shows how the active and ground electrode plates of FIG. **66** nest parallel to one another with the dielectric removed;

FIG. **69B** is another view of a similar bipolar X2Y attenuator now having a grounding metallization stripe over the entire outside surface;

FIG. **69C** is a sectional view taken along lines **69C-69C** from the structure of FIG. **69B**;

FIG. **69D** is the electrical schematic of the X2Y attenuator of FIGS. **66-69C**;

FIG. **70A** is a top view of another embodiment of the X2Y attenuator in FIGS. **66-69D** now disposed on a circuit board disposed over an insulator and ferrule;

FIG. **70B** is a cross-sectional view taken along lines **70B-70B** from the structure of FIG. **70A**;

FIG. **70C** is a top view of another embodiment of an X2Y attenuator disposed in a tombstone mounting position over an insulator and a ferrule;

FIG. **70D** is an enlarged view taken along lines **70D-70D** from FIG. **70C** showing just one of the X2Y attenuators where the active and ground electrode plates are now visible;

FIG. **71A** illustrates an isometric view of a gold pocket-pad electrically connected to the ferrule for use with the present invention;

FIG. **71B** illustrates the structure of FIG. **71A** now with a capacitor of the present invention installed;

FIG. **71C** is a view similar to FIG. **71B** now illustrating how the capacitor can be oversized such at least one of its ends can extend past the edge of the ferrule;

FIG. **72A** is a view similar to FIG. **71A** now illustrating a novel gold pocket-pad extending the long side of the ferrule thereby facilitating attachment of a larger capacitor;

FIG. **72B** is a view similar to FIG. **72A** now illustrating the capacitor attached;

FIG. **72C** is a view similar to FIG. **72B** now illustrating the capacitor metallization being grounded to the gold braze of the insulator;

FIG. **73** is a cross-sectional view taken along lines **73-73** of FIG. **72B**;

FIG. **74A** is a perspective view of an internally grounded feedthrough capacitor of the present invention before it is installed onto the ferrule;

FIG. **74B** is a view similar to FIG. **74A** now showing the electrode plate stack up;

FIG. **74C** is a view similar to FIGS. **74A** and **74B** now showing the internally grounded feedthrough capacitor installed;

FIG. **75** is a top view illustrating how a rectangular capacitor can overhang the ferrule;

FIG. **76** is a cross-sectional side view taken along lines **76-76** from FIG. **75**;

FIG. **77** is a cross-sectional side view of another embodiment of the present invention utilizing a cermet disposed within a via hole in the insulator along with an internally

grounded capacitor utilizing the gold pocket-pad for the oxide-resistant connection to the ferrule;

FIG. **78** is a cross-sectional view very similar to FIG. **77** now showing the use of an anisotropic film for making electrical connection on the device side;

FIG. **79** is a cross-sectional side view illustrating a variety of filled vias utilizing co-fired fills that can be used with the present invention;

FIG. **80** is a top view of another embodiment of a filtered feedthrough of the present invention;

FIG. **81** is a sectional top view taken along lines **81-81** of FIG. **82**;

FIG. **82** is a cross-sectional side view taken along lines **82-82** of FIG. **80**;

FIG. **83** is a cross-sectional side view taken along lines **83-83** of FIG. **80**;

FIG. **84** is a cross-sectional side view illustrating the use of a metal addition for an oxide resistant attachment;

FIG. **85** is cross-sectional side view of another embodiment of the present invention utilizing a two-part pin extending through the insulator;

FIG. **86** is a flow chart including a novel pressing step for a co-fired insulator assembly having a conductive composite sintered paste via for achieving improved hermeticity and durability;

FIG. **87** is a cross-sectional view of the insulator assembly in the green state of FIG. **87** before pressing; and

FIG. **88** is a cross-sectional view of the structure of FIG. **88** after the pressing step resulting in a mixing zone between the different structures.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** illustrates various types of active implantable medical devices (AIMD) referred to generally by the reference numeral **100** that are currently in use. FIG. **1** is a wire formed diagram of a generic human body showing a number of exemplary implanted medical devices. Numerical designation **100A** is a family of implantable hearing devices which can include the group of cochlear implants, piezoelectric sound bridge transducers and the like. Numerical designation **100B** includes an entire variety of neurostimulators and brain stimulators. Neurostimulators are used to stimulate the Vagus nerve, for example, to treat epilepsy, obesity and depression. Brain stimulators are similar to a pacemaker-like device and include electrodes implanted deep into the brain for sensing, for example, the onset of a seizure and also providing electrical stimulation to brain tissue to prevent a seizure from actually happening. Numerical designation **100C** shows a cardiac pacemaker which is well-known in the art. Numerical designation **100D** includes the family of left ventricular assist devices (LVAD's), and artificial hearts, including the artificial heart known as the Abiocor. Numerical designation **100E** includes an entire family of drug pumps which can be used for dispensing of insulin, chemotherapy drugs, pain medications and the like. Drug pumps are evolving from passive devices to ones that have sensors and closed loop systems. For example, insulin pumps provide real time monitoring of blood sugar levels and can dispense insulin in accordance with the insulin levels sensed. Such active pump devices tend to be more sensitive to EMI than passive pumps that have no sense circuitry or externally implanted leadwires. **100F** includes a variety of implantable bone growth stimulators for rapid healing of fractures. Numerical designation **100G** includes urinary incontinence devices. Numerical designation **100H**

includes the family of pain relief spinal cord stimulators and anti-tremor stimulators. Numerical designation **100H** includes an entire family of other types of neurostimulators used to block pain. Numerical designation **100I** includes a family of implantable cardioverter defibrillator (ICD) devices and also includes the family of congestive heart failure devices (CHF), also known in the art as cardio resynchronization therapy devices or CRT devices. Numerical designation **100J** illustrates an externally worn pack. Exemplary externally worn packs include external insulin pumps, external drug pumps, external neurostimulators and even ventricular assist devices.

Referring to U.S. Pat. No. 7,844,319, the content of which is fully incorporated herein by this reference, paragraphs **79** through **82** describe metallic structures, particularly leads, that when placed in MRI scanners, can pick up high electrical fields, which results in local tissue heating. Such local heating tends to be most concentrated at the ends of the electrical structure (either at the proximal or distal lead ends), which is a safety issue. Such heating safety issues can be addressed using the disclosed systems and methods of the present invention. A significant concern is that the distal electrodes, which are in contact with body tissue, can cause local tissue burns, and may even permanently damage tissue at the burn site.

As defined herein, an active implantable medical device (AIMD) includes any device or system that is designed to be totally or partially introduced or implanted within a human body for diagnostic or therapeutic purposes and includes at least one electronic circuitry. AIMDs may have primary or secondary (rechargeable) batteries as their energy sources. AIMDs may also harvest energy from the body either through mechanical motion, body motion, thermal energy, chemical or biochemical battery cell type effects or externally induced ultrasonic energy. An AIMD may also contain a resonant circuit whereby it captures energy from external pulsing electromagnetic field. An example of this is what is known in the industry as the Bion®. In general, AIMDs are connected to either a leadwire or are directly connected to electrodes without a leadwire wherein, these electrodes are contactable to biological cells. AIMD electrodes may be used for therapy delivery, sensing of biological signals or both. AIMDs may also be integrated with fiber optic cables and receive their power or signals optically wherein there is an optical converter which may convert the optical signals to either digital signals or to power.

A subclass of AIMDs is known as cardiac implantable electronic devices (CIEDs). CIEDs include all types of pacemakers, implantable cardioverter defibrillators, implantable loop recorders, subcutaneous ICDs and the like. Another subclass of AIMDs includes all types of neurostimulators, including, but not limited to spinal cord stimulators, deep brain stimulators, urinary incontinence stimulators and the like. An AIMD may include an external component, such as an RF transmitter, an RF telemetry device or even a worn wrist watch, which sends signals to an implanted device and its associated electrodes. In other words, the AIMD, as defined herein can have externally worn components in addition to implanted components.

In general, an AIMD usually has a housing, which is generally conductive and forms an electromagnetic shield (Faraday cage) thereby protecting one or more internal electronic circuits from undesirable electromagnetic interference (EMI). As used herein, the body fluid side of an AIMD is defined as the exterior or the outside of the AIMD housing. Any components residing on the outside of an AIMD housing are on the body fluid side of the AIMD (e.g.,

header block, therapy delivery leads). The device side of the AMID, also known as an inboard side, is defined as the interior of or the inside the AIMD housing. Any components or electronic circuits residing within an AIMD housing are on the device side of the AIMD (e.g., AIMD active electronic circuit board, the battery and/or capacitor).

It is understood by those skilled in the art that the use of the term body fluid side and device side can be applied to the filter feedthrough assembly before it is installed into the housing of the AIMD. It is known and shown throughout this specification that the filter capacitor is generally installed on the device side of the feedthrough, however, can alternatively be installed on the body fluid side of the feedthrough.

As used herein, the terms insulator substrate and insulator body are synonymous and can be used interchangeably. Furthermore, the terms dielectric, dielectric substrate and dielectric body are synonymous and can be used interchangeably.

As used herein, the word "adjacent" means either adjoining a structure, attached to an adjacent structure, or near an adjacent structure. For example, FIG. **78** describes a capacitor **140** that is mounted adjacent to the ferrule **134** or the insulator **156**. Mounted adjacent to the ferrule, in this context, can mean mounted right on the ferrule, mounted right on the insulator or spaced by an air gap or spaced by some sort of an adhesive washer or the like. In this context, adjacent has a broad meaning, simply meaning that the capacitor has to be near or on one of the ferrule or the insulator. Throughout the specification, the word "adjacent" means next to, adjoining, contiguous, on, neighboring, approximate or even slightly spaced away from (such as lying near).

As used herein, the conductive composite paste fill takes on the shape of the insulator passageway within which it is disposed. Post sintering, the paste fill becomes a conductive composite sintered paste fill which forms a solid conductive structure. The conductive composite sintered paste fill conformally forms a hermetic seal within the insulator passageway, thereby separating the body fluid side of the hermetic seal from the device side of the hermetic seal. To one skilled in the art, it is understood that the conductive composite paste fill before sintering does not have a defined shape, but rather is a thick, soft, moist paste filling an insulator passageway. After sintering, the paste takes on a defined shape conformal with that of the insulator passageway.

As used herein, the lead means an implanted lead, including its conductors and electrodes, the electrodes being contactable with body tissue. In general, for an AIMD, the term lead means the lead that is outside of the AIMD housing and is implanted or directed into body tissues. The term leadwire as used herein refers to the wiring or circuit traces that are generally inside of the active implantable medical device (AIMD) and are not exposed directly to body fluids.

FIG. **2** illustrates an AIMD patient **102** about to be conveyored into an MRI scanner **104**. Imaging processing equipment is shown as **106**.

FIG. **3** is a side view showing the AIMD patient **102** within the bore of an MRI scanner **104**. An intense RF-pulse field **108** is generated by the scanner's bird cage coil. As can be seen, this RF field is impinging on both the implanted cardiac pacemaker **100C** and its associated leads **110**.

FIG. **4** is a top view of the AIMD patient **102** inside the bore of the MRI scanner **104**. As can be seen, the implanted cardiac pacemaker **100C** is in a left pectoral pocket with the leads **110** routed transvenously into the interior chambers of the human heart.

FIG. 5 is a line drawing of a human heart 112 and an implantable cardiac pacemaker 100C having dual chamber bipolar leads 110 shown in the right ventricle 114 and the right atrium 116.

Referring once again to FIG. 5, as previously mentioned, it is very important that the leads 110 of the implantable cardiac pacemaker 112 do not overheat during MRI procedures particularly at or near the distal tip electrodes 118a, 118b and ring electrodes 120a, 120b. If either or both the distal tip electrodes 118a, 118b and ring electrodes 120a, 120b become overgrown by body tissue, excessive overheating can cause scarring, burning or necrosis of the heart tissue. This can result in loss of capture (loss of pacing pulses) which can be life-threatening for a pacemaker dependent patient.

FIG. 6 is similar to FIG. 2 taken from U.S. Pat. No. 10,350,421, the content of which is fully incorporated herein by this reference. FIG. 6 illustrates a dual chamber implantable cardiac pacemaker 100C with its bipolar leads 110, 110'. The distal tip electrodes 118a and 118b and distal ring electrodes 120a and 120b of the bipolar leads 110, 110' are shown routed to a human heart. During an MRI scan, the leads 110, 110' are exposed to a powerful RF-pulse field which induces electromagnetic energy on the leads. As the leads 110, 110' are electrically connected to such electronic circuitry through the ISO Standard IS-1 or DF-1 connectors 126a, 126b, 128a, 128b of the header block 138, the electromagnetic energy induced in the leads 110, 110' can undesirably couple to sensitive electronic circuitry inside of the hermetically sealed pacemaker housing 124, thereby potentially causing dangerous AIMD malfunction. The header block 138 electrically connects leads 110, 110' to the AIMD circuit board 130 by way of the leadwires 136a through 136d of the hermetic feedthrough 132. The hermetic feedthrough 132 is shown with a metal ferrule 134, which is generally laser welded into the AIMD housing 124 of the cardiac pacemaker 100C. Leadwires 136a through 136d extend through the insulator hermetically sealed to the ferrule 134 of the hermetic feedthrough 132.

Referring once again to FIG. 6, illustrated is a hermetic feedthrough 132, which is typically laser welded into an opening 123 of the titanium housing 124 of the implantable cardiac pacemaker 100C, thereby hermetically sealing the pulse generator of the implantable cardiac pacemaker 100C. The hermetic seal of the pulse generator of the implantable cardiac pacemaker 100C keeps body fluids from getting into the inside of the pacemaker housing 124. The hermetic feedthrough 132 typically comprises an electrically conductive ferrule 134 comprising a ferrule opening 131 (not labelled) extending to a ferrule body fluid side opposite a ferrule device side and an insulator 156 residing in the ferrule opening wherein a gold braze hermetically seals the insulator to the ferrule.

FIG. 6 illustrates feedthrough conductive pathways 129 (not labelled) comprising leadwires 136a through 136d passing through an insulator passageway 149 (not labelled) in non-conductive relation with the ferrule 134 of the hermetic feedthrough 132, the leadwires 136a through 136d extending to a body fluid side and a device side of the implantable cardiac pacemaker 100C. The hermetic feedthrough 132 of the implantable cardiac pacemaker 100C may comprise a glass, a glass-ceramic, or a ceramic insulator 156. The hermetic feedthrough further comprises a leak rate no greater than 1×10^{-7} std cc He/sec. As illustrated in FIG. 6, the hermetic feedthrough 132 comprises a feedthrough filter capacitor 140, which is mounted adjacent to one of the ferrule 134, the insulator 156 or both the ferrule

and the insulator of the hermetic feedthrough 132. An embodiment of an exemplary hermetic feedthrough 132 comprises an alumina insulator 156 gold brazed to a titanium ferrule 134, the insulator comprising at least one insulator passageway 149 disposed through the insulator 156. The at least one insulator passageway 149 extends to a body fluid side and to a device side of the insulator 156. The at least one insulator passageway 149 comprises a feedthrough conductive pathway 129 disposed therewithin, the feedthrough conductive pathway 129 being hermetically sealed to the at least one insulator passageway. The feedthrough conductive pathway 129 comprises an electrical conductor. The electrical conductor of the hermetic feedthrough 132 is selected from the group consisting of a leadwire, a lead wire, a terminal pin, a pin, a two-part pin, a lead conductor, a sintered conductive via, a sintered paste-filled via, a co-sintered via, a co-sintered paste-filled via, a co-sintered via with one or more metallic inserts, or combinations thereof. FIGS. 7 and 8 provide another exemplary hermetic feedthrough embodiment in accordance with the teachings of FIG. 6.

FIGS. 7 and 8 illustrate an exemplary rectangular quad polar (planar array) feedthrough filter capacitor 140 mounted to the hermetic feedthrough 132 of a cardiac pacemaker in accordance with U.S. Pat. No. 5,333,095 to Stevenson et al., the content of which is fully incorporated herein by this reference. It is understood that a feedthrough filter capacitor 140 may be mounted adjacent to one of the ferrule 134, the insulator 156, or both the ferrule and the insulator of the hermetic feedthrough 132. Once a filter capacitor is placed on the hermetic feedthrough 132, then the assembly is considered a filtered feedthrough 122.

As illustrated in FIGS. 7 and 8, in a typical broadband or lowpass EMI filter construction, a ceramic feedthrough filter capacitor 140 is electrically connected to a hermetic feedthrough 132 to suppress and decouple undesired interference or noise transmission along one or more terminal pins 142. The feedthrough filter capacitor 140 comprises active electrode plates 144 and ground electrode plates 146, which are embedded in spaced relation within a dielectric body 148. The feedthrough filter capacitor 140 is typically formed as either a ceramic monolithic or a ceramic multi-layered structure. The active electrode plates 144 are electrically connected to an inner diameter cylindrical surface to an active capacitor metallization 164 of the feedthrough filter capacitor 140 and to the active terminal pins 142 so that the desired electrical signal or signals may pass along an active conductive path (FIG. 11 illustrates the electrical schematic diagram). The ground electrode plates 146 are electrically coupled to a ground capacitor metallization 166 at a sidewall of the dielectric body 148, the ground capacitor metallization in this embodiment being an outer edge metallization of the feedthrough filter capacitor 140. The ground capacitor metallization 166 is shown electrically connected to a gold pocket-pad 158 of a rectangular electrically conductive ferrule 134 using an electrically conductive material 152. The gold pocket-pad 158 embodiment of FIG. 8 is a part of the gold braze 154a hermetically sealing the insulator 156 of the hermetic feedthrough 132 to the ferrule 134. It is noted that the structure of the gold pocket-pad 158 may be a separate pocket structure from the gold braze hermetically sealing the insulator to the ferrule or may be a gold pocket-pad area that is a structural extension of the gold braze hermetically sealing the insulator to the ferrule as shown in FIG. 8. As used herein, a gold pocket-pad that is separate from the gold braze hermetically sealing the insulator to the ferrule and a gold pocket-pad area that is a structural

extension of the gold braze hermetically sealing the insulator to the ferrule each provide oxide-resistant electrical attachment to a feedthrough filter capacitor 140. In the prior art, without regard to high frequency capacitor ESR, the number and dielectric thickness spacing of the active electrode plates 144 and the ground electrode plates 146 will vary in accordance with the capacitance value and the voltage rating of the feedthrough filter capacitor 140.

In operation, the coaxial feedthrough filter capacitor 140 permits passage of relatively low frequency electrical signals along the terminal pins 142, while also shielding and decoupling/attenuating undesired interference signals of typically high frequency to the conductive housing 124. Feedthrough filter capacitors 140 of this general type are available in unipolar (one), bipolar (two), tripolar (three), quad polar (four), pentapolar (five), hexpolar (6), "n" polar and can be designed to accommodate various terminal pin design configurations and/or terminal pin design layouts. Such feedthrough filter capacitors 140 can further be of various shapes, for example, round, oval, rectangular, discoidal and even custom configurations. Such feedthrough filter capacitors 140 are commonly employed in active implantable medical devices (AIMD) such as implantable cardiac pacemakers, defibrillators, neurostimuators and the like, wherein the AIMD housing 124 of these AIMDs is constructed from a biocompatible metal such as, but not limited to, titanium or a titanium alloy. As a result, the filter capacitor and hermetic feedthrough prevent entrance of interference signals to the interior of the pacemaker housing 124, wherein such interference signals can otherwise adversely affect the desired cardiac pacing, defibrillation or neurostimulation function.

As illustrated in FIG. 7, the electrically conductive material 152 (for example, an electrically conductive polyimide, an electrically conductive adhesive, an electrically conductive epoxy, an electrically conductive thermal-setting polymer or a solder) connects the ground capacitor metallization 166 and the gold pocket-pad area 158. The gold pocket-pad area 158 forms a metallurgical bond with the titanium of the ferrule 134 of the hermetic feedthrough 132 and precludes any possibility of an unstable oxide forming. Gold is a noble metal that does not readily oxidize and remains very stable even at elevated temperatures. The novel gold braze structure and construction methodology illustrated in FIG. 7 guarantee that the ohmic losses of the feedthrough filter capacitor 140 will remain very small at all frequencies. By connecting the ground electrode plates 146 of the feedthrough filter capacitor 140 to a low resistivity oxide-resistant material such as the gold pocket-pad area 158, one is guaranteed that this electrical connection will not substantially contribute to the overall ESR of the feedthrough filter capacitor 140. Keeping the ESR of the feedthrough filter capacitor 140 as low as possible is very important for diverting a high amount of RF current such as is induced in the AIMD lead system during MRI scanning. One is referred to U.S. Pat. No. 6,765,779 to Stevenson et al. for additional information on electrically connecting to oxide-resistant materials, the content of which is fully incorporated herein by this reference.

FIG. 8 is a cross-section of feedthrough filter capacitor 140 and the hermetic feedthrough 132 of FIG. 7. One can see that the gold braze 154a that forms the hermetic seal between the alumina insulator 156 and the titanium ferrule 134 is desirably on the feedthrough capacitor side. This makes it easy to manufacture the gold pocket-pad area 158 for convenient attachment by the electrically conductive material 152. In other words, designing the gold pocket-pad

area 158 on the same side as the gold braze 154a hermetically sealing the insulator 156 to the ferrule 134 permits the gold pocket-pad 158 to be co-formed at the same time as the gold braze 154a is formed in one manufacturing operation in a gold braze vacuum furnace regardless of whether the gold pocket-pad area is structurally a part of the gold braze hermetic seal or a separate gold pocket-pad spaced apart from the gold braze hermetic seal. FIG. 8 also illustrates an insulative material 160 (which can be an insulating washer) disposed between the feedthrough filter capacitor 140 and the underlying hermetic feedthrough 132. As illustrated, the insulator 156 is at least partially disposed within a ferrule opening 131. Also shown is an insulator passageway 149 formed in the insulator 156 allowing a terminal pin 142 or a leadwire 136 (such as illustrated in FIG. 6) to be hermetically sealed by gold braze 152b. The terminal pin 142 of FIG. 8 extends to the body fluid and device sides of the hermetic feedthrough 132. The device side portion of the terminal pin 142 further extends through a capacitor conductive pathway 150 of a feedthrough filter capacitor 140.

FIG. 9 is a quad polar feedthrough filter capacitor 140 mounted to a hermetic feedthrough 132 similar to that described in FIG. 7 except that, in this case, the filter capacitor structure is round or discoidal. It is understood that a filtered feedthrough may comprise any filter capacitor shape instead of a round or discoidal filter capacitor, such as oval, rectangular, square and custom designed filter capacitor shapes.

FIG. 10 is a cross-sectional view taken generally from section 10-10 of FIG. 9. There are four feedthrough terminal pins 142 each residing in a feedthrough conductive pathway 129, which extend through the feedthrough filter capacitor 140. The feedthrough filter capacitor comprises ground electrode plates 146 and active electrode plates 144.

As shown in FIG. 10, there are only three active electrode plates 144 and four ground electrode plates 146. This low electrode plate count results in a feedthrough filter capacitor 140 that has a relatively high ESR at high frequencies. In an experiment conducted by the inventors, a typical EIA X7R 400-picofarad capacitor with only four electrode plates had an ESR at 64 MHz of 4.8 Ohms. Re-design of the same geometry (size) capacitor with an EIA NP0 dielectric for a 400-picofarad capacitor with over 20 electrode plates resulted in an ESR at 64 MHz of approximately 300 milliohms (0.3 Ohms). This sixteen to one reduction at 64 MHz is a dramatic illustration of the importance of designing the AIMD MRI diverter feedthrough filter capacitor 140 for low ESR. For example, for an X7R capacitor, the impedance is the square root of the sum of the capacitor's reactance squared plus the ESR squared. A 400-pF capacitor has a reactance of 2.49 ohms at 64 MHz. This results in a capacitor impedance Z which is equal to $-j2.49+4.8$ or approximately 5.41 Ohms. Assuming an MRI induced RF voltage at the AIMD input at 64 MHz of 10 Volts, the RF current diverted through the X7R capacitor is 10 Volts divided by 5.41 Ohms which is 1.85 Amps. The power dissipation due to the X7R capacitor's ESR (I^2R) is $(1.85)^2(4.8)=16.43$ Watts. This amount of power dissipation is excessive for such a small component and will cause a temperature rise of over 20° C. On the other hand, a 400-pF NP0 capacitor's impedance is equal to $-j2.49+0.3$ or $Z=2.51$ Ohms. This lower impedance will result in a much better filter (higher attenuation) and will drop the RF voltage from 10 Volts to approximately 3.71 Volts. This voltage drop is caused by the lead's characteristic impedance and the fact that more current has been drawn through this impedance. This causes a voltage drop in the lead's characteristic impedance as measured at the input

to the AIMD. The RF current through the NP0 capacitor is then 3.71 Volts divided by Z of 2.51 Ohms which is 1.48 Amps. The power dissipation (I^2R) is (1.48 Amps)^2(0.3 Ohm) which equals 0.66 Watts which will result in a much smaller temperature rise. Accordingly, the low ESR diverter feedthrough filter capacitor design (FIG. **32** labelled **210** and FIG. **34** labelled **210'**) of the present invention offers the following advantages: (1) a much lower impedance at 64 MHz and therefore a more effective EMI filter; (2) higher attenuation, therefore acts to reduce the MRI induced RF voltage at the input to the AIMD; and (3) as will be shown, the diverter feedthrough filter capacitor **210, 210'** can be designed to conduct or convect heat away for dissipation over a larger surface area.

The above examples of ESR and impedance are just illustrative examples of many thousands of possibilities. For active implantable medical devices, in general, capacitance values range anywhere from 300-pF to 15,000-pF. Each design has a different physical geometry, size and number of internal electrode plates. In other words, there are many other examples that have different values of ESR. The general principles illustrated above, however, do apply across the board for all such capacitor design variations. Low k dielectrics will always mean a higher number of electrode plates and therefore a lower ESR. That means that the low ESR designs will have much less heating of the capacitor itself in an MRI environment.

The feedthrough filter capacitor **140** is bonded with an insulating washer **162** (which comprises an insulative material) to the hermetic feedthrough **132**. An electrically conductive material **152**, such as an electrically conductive polyimide, an electrically conductive adhesive, an electrically conductive epoxy, an electrically conductive thermal-setting polymer or a solder, attaches the outside diameter ground capacitor metallization **166** of the feedthrough filter capacitor **140** and the gold braze **154***a*. The necessity to make an oxide-resistant (that is, an essentially oxide-free) attachment between the feedthrough filter capacitor **140** and the ferrule **134** is described in U.S. Pat. No. 6,765,779, the content of which is fully incorporated herein by this reference. The insulator **156** of FIG. **10**, such as an alumina ceramic, is hermetically sealed to the ferrule **134** by means of a gold braze **154***a*. It is understood that the insulator **156** may alternatively comprise a glass or a glass-ceramic, which may form either a hermetic compression seal or a hermetic matched seal. As glass-based seals are generally fusion seals, instead of a hermetic gold braze **154***a*, an oxide-resistant pocket-pad or a gold pocket-pad area **158** such as disclosed by FIG. **8** is used to make an oxide-resistant attachment to the feedthrough filter capacitor **140**. The four terminal pins **142** of FIG. **10** are hermetically sealed to the insulator **156** via gold braze **154***b* (as there are four terminal pins **142**, there are four gold brazes **154***b*), each brazed terminal pin forming a feedthrough conductive pathway **129**. The four terminal pins **142** are attached to the active electrode plates **144** of the feedthrough filter capacitor **140** using an electrically conductive material **168**, such as an electrically conductive polyimide, an electrically conductive adhesive, an electrically conductive epoxy, an electrically conductive thermal-setting polymer or a solder. The electrically conductive material **168** electrically connects the active capacitor metallization **164**, which is electrically connected to the active electrode plates **144** of the feedthrough filter capacitor, thereby forming four capacitor conductive pathways **150**, each conductive pathway comprising one of the four terminal pins **142** of the hermetic feedthrough **132**.

Referring once again to FIG. **8**, one can see that there are only two active electrode plates **144** and two ground electrode plates **146**. A low electrode plate count is typically the case for prior art feedthrough filter (diverter) capacitors **140** used in AIMD applications such as cardiac pacemakers, ICDs and the like, so that a capacitance value is generally kept low, as a high capacitance value loads down the output of an AIMD. For example, too high of a capacitance value distorts pacemaker therapeutic pulses and also rob energy from the active implantable medical system. An even more extreme example is in the case of an implantable cardioverter defibrillator, where a filter capacitance value is too high such that the high voltage monophasic or biphasic shock wave form is seriously degraded. In the experience of the inventors, the capacitance value for an AIMD diverter feedthrough filter capacitor **140** is in a relatively narrow range from 10 picofarads to 20,000-picofarads. In most cases, the capacitance value is between 350 picofarads and 10,000-picofarads. Having a capacitance value between these ranges effectively attenuates most emitters from which AIMDs can be affected. This includes microwave ovens, cellular telephones and the like, which typically operate in the GHz frequency range. The thickness **170** of the feedthrough filter capacitor **140**, however, cannot be below a certain minimum or the barium titanate based ceramic capacitor dielectric body **148** becomes too fragile. The entire hermetic feedthrough **132** and the feedthrough filter capacitor **140** must be able to withstand thermal cycles and shocks including installation of the filtered feedthrough into the AIMD housing **124** by a laser weld **157**. Accordingly, it is very unusual to see the thickness **170** of a diverter feedthrough filter capacitor **140** less than 20/1000 of an inch (0.020 inches or 20 mils). Notwithstanding, when one looks at a cross-section of a typical prior art feedthrough filter capacitor **140** for human implant, one sees that there are very few electrode plates **144, 146** relative to the overall thickness **170** of said feedthrough filter capacitor. In fact, there are usually a number of blank dielectric cover sheets/layers **172** (blank meaning that there are no electrode plates on the dielectric cover sheets/layers) added on the top and/or bottom of the feedthrough filter capacitor **140** consisting of ceramic material which is co-fired to add mechanical strength. There is a serious downside, however, to having very few electrode plates **144, 145**, and that is that the high frequency equivalent series resistance (ESR) of the capacitor increases. For example, prior art AIMD diverter feedthrough filter capacitors **140** having significant dielectric and/or ohmic resistance at high frequencies simply does not matter. This is because the power induced from a typical emitter, such as a cellular telephone or microwave oven results in a trivial amount of RF current flowing through the diverter feedthrough filter capacitor **140**. Even in the most extreme examples, only a few milliwatts of heat is generated within the capacitor structure itself. For high power RF current handling applications, however, for example, MRI conditional AIMDs that require diverting of the MRI induced RF energy, the capacitor dielectric loss and high frequency ESR become critical and must be kept as low as possible. Accordingly, it is a feature of the present invention to have a relatively high number of electrode plates **144, 146** (generally greater than 10 active and 10 ground). It is noted, however, that a high number of electrode plates in a feedthrough filter capacitor comprising a high k barium titanate based ceramic dielectric with a dielectric constant of around 2,500 as typically used in the prior art, results in a very high (too high) capacitance value. The present application resolves this issue through the use of a relatively low

dielectric constant material, such as EIA Standard NP0 material. NP0 material has a much lower k (generally, in the area of 60 to 90). A low k dielectric material is defined herein as having a k greater than 0 but less than 1,000, referred herein as k<1,000. In some embodiments, a low k dielectric material has a k greater than 0 but less than 200, k<200. In some embodiments, a low k dielectric material has a k greater than 0 but less than 100, k<100. Accordingly, in order to achieve a desired capacitance value (in the range of 350 picofarads to 10,000 picofarads or the range of 10 picofarads to 20,000 picofarads as previously disclosed), a much greater number of electrode plates is required. The higher number of electrode plates creates more parallel paths for RF current flow and greatly reduces the ESR of the feedthrough capacitor. One is referred to the equation illustrated in FIG. 22 to understand the relationship between capacitance and the number of electrode plates and other factors.

FIG. 11 is a schematic diagram of the quad polar feedthrough capacitor 140 of FIGS. 7-10. Feedthrough capacitors are three-terminal devices labelled in FIG. 11 as 141*a* (terminal 1), 141*b* (terminal 3), and 141*c* (terminal 2).

FIG. 12 is a cross-sectional view of an embodiment of a novel hermetic feedthrough installed in a housing of an AIMD taken from FIG. 17 of U.S. Pat. No. 8,653,384, the content of which is fully incorporated herein by this reference. The outer surface of the insulator 156 (which may be a ceramic insulator, for example, an alumina insulator) of the hermetic feedthrough 132 has an insulator external metallization 167 disposed at least partially on the outer surface of the insulator. The insulator external metallization 167 may comprise two metallization layers, an adhesion metallization layer and a wetting metallization layer, wherein the adhesion metallization layer may be disposed at least partially on the outside surface of the insulator 156, and wherein the wetting metallization layer may be disposed on the adhesion metallization layer so that during brazing a braze 154 (such as a gold braze) melts and hermetically bonds to the insulator 156 and the ferrule 134 of the hermetic feedthrough 132. The braze 154 contacting the insulator external metallization 167 of the insulator 156 and the electrically conductive ferrule 134 thereby forms the hermetic seal between the insulator and the ferrule. It is understood that, while two metallization layers are illustrated, the insulator external metallization 167 may only comprise one metallization layer or may comprise more than two metallization layers. The ferrule 134 may be installed into the AIMD housing 124 by forming a laser weld 157, however, other joining processes such as brazing, micro welding, micro TIG welding, ultrasonic welding, resistance welding, friction welding, butt welding, arc welding, gas welding, projection welding, flash welding, upset welding, solid state welding, diffusion welding, induction welding, percussion welding, electron beam welding, multi-stage brazing, or reactive brazing may be used. In this embodiment, instead of a feedthrough leadwire 136 or terminal pin 142, this embodiment comprises a sintered paste-filled via 142'. It is a novel feature of this embodiment that this sintered paste-filled via 142' be of essentially pure platinum that is co-fired with the essentially high purity alumina ceramic substrate 156. As will be shown later, a ceramic reinforced metal composite (CRMC) may alternatively be used instead of a high purity platinum to form the sintered paste-filled via. Such sintered paste-filled vias offer customizable feedthrough conductive pathways design options while providing ease of manufacturing and cost-effective feedthrough design alternatives.

In general, hermetically sealed AIMDs have a body fluid side and a device side. As used herein, the device side (inboard side) is located inside the conductive housing 124 of the AIMD, and the body fluid side is located outside the conductive housing 124 of the AIMD. After laser welding a hermetic feedthrough 132 to the conductive housing 124 of the AIMD, the feedthrough conductive pathways 129 (not labelled in FIG. 12), which comprise an electrical conductor, pass through the conductive pathway 129 to a body fluid side and to a device side. As previously disclosed, an electrical conductor of a hermetic feedthrough 132 may be selected from the group consisting of a leadwire, a lead wire, a terminal pin, a pin, a two-part pin, a lead conductor, a sintered conductive via, a sintered paste-filled via, a co-sintered via, a co-sintered paste-filled via, a co-sintered via with one or more metallic inserts, or combinations thereof. Thus, the feedthrough conductive pathway 129 through the insulator 156 of the hermetic feedthrough 132 between the body fluid side and the device side can be made from a leadwire 136, a terminal pin 142 or, as shown in FIG. 12, a conductive sintered paste-filled via 142'. The conductive pathway 129 between the body fluid side and the device side can also be a combination of conductive inserts co-sintered within conductive pastes of the sintered past-filled via 142'. Accordingly, the distal end of the feedthrough conductive pathways 129 on the body fluid side are external of the AIMD housing 124 (hence is exposed to body fluid) and the opposite distal end of the feedthrough conductive pathways 129 on the inboard side or device side is located inside of the AIMD housing (hence is connectable to the AIMD electronic circuits residing internal to the AIMD housing).

FIG. 13 is a cross-sectional view of another embodiment taken from FIG. 22 of U.S. Pat. No. 8,653,384, showing a hermetic feedthrough 132 and an attached filter 140 having a coated (metallized) bore filled with electrically conductive material and a coated (metallized) bore without any fill in the bore. One is directed to U.S. Pat. No. 8,179,658, the content of which is fully incorporated herein by this reference, which illustrates a capacitor bore and a solid feedthrough leadwire in the capacitor bore. In this embodiment, the capacitor bore has no metallization, and the solid feedthrough leadwire is directly connected to the capacitor active electrode plates by only the electrically conductive material filling the un-metallized capacitor bore. Referring to the embodiment of FIG. 13, the feedthrough filter capacitor 140 is mounted directly to one or more of the co-sintered platinum filled vias of the insulator of the hermetic feedthrough as shown in the exemplary co-sintered filled vias 142*a*', 142*b*' of FIG. 13. In this embodiment, an adhesively backed insulator washer 153 is used to affix the feedthrough filter capacitor 140 onto the surface of the alumina substrate 156.

There are two different methods of electrical attachment to the feedthrough filter capacitor illustrated in FIG. 13. In the left-hand capacitor bore, there is a solid fill of, for example, a solder, a braze or a thermal-setting conductive material 155. Such a solid fill capacitor bore may also be used for connection in the embodiments of the '658 patent, which have no capacitor bore metallization. A simplified electrical attachment is shown on the right-hand capacitor bore, wherein a solder bump or ball grid array (BGA) 151 is first dispensed at the metallized but un-filled capacitor bore and then the filter capacitor is aligned and placed over co-sintered paste-filled vias of the hermetic feedthrough as shown. Then, a temperature is applied to reflow the solder into place. The solder makes electrical contact with the co-sintered paste-filled filled via 142*a*', 142*b*' and also with

the active capacitor metallizations (terminations) 164 of the metallized un-filled capacitor bore.

In accordance with good EMC principles, the feedthrough filter capacitor 140 is disposed immediately at the point of EMI ingress into the inside of the device housing 124. In this way, high frequency EMI can be decoupled and diverted to the device housing 124 without adversely affecting AIMD sensitive electronic circuits. Feedthrough filter capacitor active electrode plates 144a and 144b are both each connected to the active capacitor metallization 164 of their respective capacitor bores. The capacitor ground electrode plates 146 make contact with the ground capacitor metallization 166. An electrically conductive material 152 provides electrical connection to the ground capacitor metallization 166 and to the gold braze 154 of the ferrule 134, which makes a low impedance and low resistance essentially oxide-free electrical connection, required for superior high frequency performance.

FIG. 14 is a prior art multi-layer ceramic capacitor (MLCC) 140'. MLCC chip capacitors are made by the hundreds of millions per day to service consumer electronics and other markets. Virtually all computers, cell phones and other types of electronic devices have many MLCC chip capacitors. One can see that the MLCC chip capacitor 140' has a body generally consisting of a high dielectric constant ceramic body 148' such as barium titanate. The MLCC chip capacitor 140' also has a pair of solderable terminations (the active capacitor metallization 164 and the ground capacitor metallization 166) at either end. These solderable active and ground terminations, that is the active capacitor metallization 164 and the ground capacitor metallization 166, provide a convenient way to make an electrical connection to the internal electrode plates 144, 146 of the MLCC chip capacitor 140'. The filter capacitors of FIG. 14 can also comprise other shapes and types of filter capacitor technologies, including rectangular, cylindrical, round, tantalum, aluminum electrolytic, stacked film or any other such capacitor shapes and technologies. It is understood by those skilled in the art that the MLCC chip capacitor 140' can be flipped such that the corresponding capacitor metallizations 164 and 166 are reversed, as it is only when the MLCC chip capacitor 140' is installed that one can identify which metallization is the active capacitor metallization 164 and which metallization is the ground capacitor metallization 166.

FIG. 15 is a cross-sectional view taken from section 15-15 of FIG. 14. The MLCC 140' includes left-hand side electrode plates 144 and right-hand side electrode plates 146. One can see that the left-hand side electrode plates 146 are electrically connected to an external capacitor metallization 164. The right-hand side electrode plates 146 are shown connected to the external capacitor metallization 166. Prior art MLCC 140' and equivalent chip capacitors are also known as two-terminal capacitors. That is, there are only two ways electrical energy can connect to the body of the capacitor. In FIGS. 14 and 15, the first terminal 174 is on the left-hand side and the second terminal 176 is on the right-hand side of the capacitor. As defined herein, MLCC chip capacitors are two-terminal devices. In contrast, feedthrough filter capacitors are three-terminal devices, which have very low self-inductance and make excellent high frequency EMI filters.

FIG. 16 is the schematic diagram of the MLCC 140' illustrated in FIGS. 14 and 15.

FIG. 17 illustrates another type of prior art three-terminal filter capacitor known as a flat-through capacitor 140". The flat-through capacitor 140" is connected to circuit traces 178a, 178b at active capacitor metallizations 164a, 164b at

each end of the flat-through capacitor forming an active circuit path. A circuit current 180 passes all the way through the capacitor 140" along the active circuit path as illustrated. The capacitor 140" is also connected to ground circuit traces 182a, 182b at ground capacitor metallizations 166 forming a ground circuit path. The overlap of the active electrode plates and the ground electrode plates creates the capacitance of the flat-through capacitor 140".

FIG. 18 illustrates the internal electrode plates of the flat-through capacitor 140" of FIG. 17. Ground electrode plates 146 are connected to ground capacitor metallizations 166. The through active electrode plates 144 are connected to active capacitor metallizations 164a, 164b. The electrode plate embodiment of the flat-through capacitor 140" of FIG. 17 comprises a through or active electrode plate 144 sandwiched between two ground electrode plates 146. As previously disclosed, the through or active electrode plate 144 is connected at both ends of the flat-through capacitor by the active capacitor metallizations 162a, 162b, which are terminals 1 and 2 respectively of the flat-through capacitor 140". When the flat-through capacitor is mounted between the circuit traces 178a, 178b as shown in FIG. 17, the active circuit path is made. Referring to the active electrode plate of FIG. 18, one can see the current i_1 enters at 164a (terminal 1). If the current is a high frequency EMI current, it is attenuated along the length of the flat-through capacitor by the capacitance of the flat-through capacitor and emerges as a much smaller amplitude EMI signal at 164b (terminal 2) as current $i_{1'}$.

FIG. 18A is the schematic of the three-terminal flat-through capacitor of FIG. 17. One can see that the flat-through capacitor is a true three-terminal device consisting of terminals 164a (terminal 1), 164b (terminal 2) and ground 166 (terminal 3). The circuit current 180 passes through the active electrode plate 144 from the first terminal 164a to the second terminal 164b. The ground terminal which is the third terminal, is the AIMD housing 124. As shown, the circuit current i_1-$i_{1'}$ passes all the way through the flat-through capacitor, as illustrated.

FIG. 19 illustrates a method of attaching MLCCs 140' directly to the hermetic feedthrough 132. In accordance with the present invention, the MLCCs 140' are relatively low dielectric constant (low k), like NP0, such that they have a high number of electrode plates thereby minimizing capacitor ESR. This makes MLCC chip capacitors very effective in diverting high levels of RF current at an MRI RF-pulse frequency. One is referred to U.S. Pat. Nos. 5,896,267 and 5,650,759, both to Hittman et al., which more thoroughly describe the use of MLCC chip capacitors as feedthrough filter capacitors attached at or near the hermetic feedthrough of an active implantable medical device. The contents of these two patents are fully incorporated herein by these references.

FIG. 19A is the schematic diagram of the bipolar MLCC chip capacitors 140' of FIG. 19. As shown, these are two-terminal capacitors with terminal 1 connected to the terminal pin 142 and terminal 2 connected to ground, which is also the AIMD housing 124.

FIG. 20 is a cross-section of a typical MLCC chip capacitor 140', such as those of FIGS. 14 and 19. It is noted, as previously disclosed, that the ESR of the capacitors of FIGS. 14 and 19 is high due to a low number of electrode plates 144, 146. The design principles illustrated in this cross-section are equally applicable to any type of feed-through filter capacitor 140, including the filter capacitors described in FIGS. 7 and 9 of the present application. In general, the equivalent series resistance (ESR) of a filter

capacitor depends upon a number of very important variables. A filter capacitor's ESR is the sum of the connection resistance (R$_c$) **184**, the resistance of attachment material (R$_a$) **186**, the resistance of capacitor metallization (used to attach to internal electrode plates) (R$_m$) **188**, the electrode resistance (R$_e$) **190** and **190'** of the electrode plates **144** and **146** and also the resistance of the dielectric loss tangent (R$_{DL}$) **192**. There is also another type of resistance (not shown) which occurs at very high frequency, known as skin effect (R$_s$). Skin effect is understood by those skilled in the art as the tendency of a high-frequency current to flow near the surface of a conductor as opposed to the interior of a conductor resulting in an increase of resistance in the conductor with increasing frequency. Hence skin effect is a situation in which the bulk of the current flow is on the skin (near the surface) of the electrode plates and the circuit connections instead of uniformly distributed throughout the full body of the conductor. This also has the effect of increasing a capacitor's ESR. In general, for typical MRI RF-pulse frequencies, skin effect can be ignored (as skin effect is mostly a greater than 500 MHz phenomenon).

FIG. **21** is the schematic diagram of the MLCC chip capacitor **140'** of FIG. **20** showing that the capacitor's ESR is the sum of the connection resistance (R$_c$) **184**, the connection material resistance (R$_a$) **186**, the capacitor metallization resistance (R$_m$) **188**, the electrode resistance (R$_e$) **190** and the capacitor's dielectric loss resistance (R$_{DL}$) **192**. The capacitor's dielectric loss resistance (R$_{DL}$) **192** is frequency variable, which will be explained in further detail. For a well-designed and properly installed filter capacitor, many of these resistances are so small that they can be ignored. For example, referring once again to the MLCC chip capacitor **140'** of FIG. **20**, if the capacitor metallizations **164**, **166** are well designed and are properly attached to the filter capacitor, then the capacitor metallizations will have a trivially small resistance (R$_m$) **188**. In a similar fashion, if the electrical attachment material **152** is a solder or a proper thermal-setting conductive adhesive, the attachment material resistance (R$_a$) **186** will also be a trivial amount. If the system is attached to gold or another similar oxide-resistant material, then the connection resistance (R$_c$) **184** will also be trivially small. Referring once again to MLCC chip capacitor **140'** of FIG. **21**, the total ohmic loss R$_o$ **200**, therefore, consists almost entirely of the total electrode plate resistance (R$_e$)$_{total}$ **190 190'**. This is why it is so important in the present invention to maximize the number of electrode plates of a low k filter capacitor. A low k filter capacitor is defined herein as comprising a low k dielectric material having a k<1,000. In some embodiments, a low k capacitor comprises a dielectric material having a k<200. At high frequency, the ohmic loss of the low k filter capacitor is almost entirely due to the resistive loss of the active and ground electrode plates (R$_e$)$_{total}$ **190, 190'**.

FIG. **22** provides the equation relating capacitance C to the dielectric constant k, the active area A, which is the overlap area of the active electrode plate and the ground electrode plate of a capacitor, the number of electrode plates n and the dielectric thickness d of the filter capacitor. Since the dielectric constant k is directly related to the capacitance C, one can see how dramatically the capacitance of a capacitor rises when the dielectric constant k is 2,500 as opposed, for example, to a dielectric constant k below 200 such as an EIA Class I dielectric. Assuming a constant capacitor dielectric thickness d for a particular filter capacitor voltage rating, the only way to increase the capacitance of a filter capacitor comprising a dielectric having a k below 200 so that the original capacitance value of the filter

capacitor comprising the dielectric having a k of 2,500 is achieved requires greatly increasing the number of electrode plates in this capacitor comprising the dielectric having k less than 200. In the prior art, using a dielectric having a k less than 200 in a feedthrough filter capacitor is counterintuitive. However, in the present invention, a capacitor having a dielectric with a k less than 200 is exactly what we want to do. A high number of electrode plates drives down the high frequency ohmic losses of the filter capacitor and thereby greatly increases the efficiency of the filter capacitor comprising such low k dielectrics so that RF energy can effectively be pulled out of an implanted lead during MRI scans. In addition, the high number of electrode plates of such a filter capacitor has a very low equivalent series resistance at the MRI RF-pulse frequency, thereby significantly reducing the amount of heat produced in, for example, a low k diverter feedthrough filter capacitor **140** or a low k diverter MLCC chip capacitor **140'**.

FIG. **23** illustrates the schematics of an ideal capacitor **194** and also a real (non-ideal) capacitor **196** which consists of an ideal capacitor **194** in series with its ESR **198**. For the purpose of the present discussion, a capacitor's series inductance or insulation resistance (a parallel resistance) can both be ignored. This is because the inductance of feedthrough filter capacitors is quite low at MRI RF-pulse frequencies. Further, the filter capacitor's insulation resistance is generally in the megohms or gigohms range, which is so high, it can also be ignored as a parallel path. Also shown in FIG. **23** is a graph of the impedance plane showing the capacitor ESR in the real axis and the capacitive reactance $-jX_C$ shown on the imaginary axis. The capacitor's loss tangent δ is also illustrated.

In FIG. **24**, equations are given for capacitive reactance X$_C$, impedance Z, dissipation factor DF and loss tangent of δ, which is also defined as the dissipation factor DF. Historically, dissipation factor has been expressed as a percent, such as 2.5% maximum. This means that the allowable dissipation factor is 2.5% of a capacitor's capacitance reactance at a particular frequency. Usually, due to dielectric losses, this number is dominated at low frequencies by the capacitor's dielectric loss. The capacitor's dielectric loss is generally related to its dielectric constant and the frequency of the driving energy. For example, if the frequency of an applied sinusoid is relatively low (say 60 Hz), then the crystal lattice of the capacitor has plenty of time to deflect back and forth under the electrical stress and, in so doing, produces a significant amount of heat, which is a type of real or resistive loss. At 1 kHz, the capacitor dielectric structure (or dipoles, if one uses that theory) vibrates at a higher frequency. As one goes higher and higher in frequency, say to 10 MHz, then for the low k Class I dielectrics of the present invention, there is very little movement in the crystal lattice and, accordingly, very little heat generated due to dielectric loss. It will be further illustrated how dielectric loss varies with frequency. In the past, particularly as described by testing specifications such as MIL-STD-202 and MIL-STD-220 among others, dissipation factor is measured either at 1 kHz, or in some cases, at 1 MHz. Unfortunately, this data is misleading at MRI RF-pulse frequencies, which generally are 21.28 MHz (0.5 T), 64 MHz (1.5 T), 128 MHz (3 T) or higher. For most dielectrics, the high frequency ohmic loss, due to the capacitor's electrode plates, is so low that it is masked by the capacitor's dielectric loss when measured at low frequencies such as 1 kHz or 1 MHz. This will be explained in subsequent figures.

FIG. **25** is a more complete schematic for an MLCC chip capacitor **140'**, which has been simplified from FIG. **21**. (R$_o$)

represents total ohmic loss **200** which is the sum of the ohmic losses by connection resistance (Re) **184**, the attachment material resistance (R_a) **186**, the metallization resistance (R_m) **188**, and the electrode resistance (R_e) **190**. Assuming that the connection resistance (R_c) **184** is very low, such as in an attachment to gold, and that the attachment material resistance (R_a) **186** has a very low resistivity, such as a thermal-setting conductive adhesive or a solder, and assuming that the capacitor metallization materials have very little ohmic resistance to the electrode plates, then one can assume that the bulk of the total ohmic loss (R_o) **200** of the MLCC chip capacitor **140'** is equal to the entire electrode stack of said MLCC chip capacitor, meaning that the total ohmic loss (Ro) **200** is essentially equal to the electrode resistance $(R_e)_{total}$ **190** of the MLCC chip capacitor **140'**. As previously disclosed, the resistance of the electrode stack of the capacitor depends on the length, the width and the thickness of the electrode plates and also, importantly, on the number of electrode plates that are in parallel. Therefore, reducing the dielectric loss and maximizing the number of electrode plates are key features of the filter capacitor embodiments of the present invention.

FIG. **26** is a simplified schematic diagram of FIG. **25** showing that the ESR **198** of the MLCC chip capacitor **140'** is the sum of the dielectric loss tangent resistance (RDL) **192** plus the total electrode resistance $(R_e)_{total}$ **190** of the parallel electrode stack of said MLCC chip capacitor. Referring once again to FIG. **25**, one can see that there is a resistor in parallel with the ideal capacitor C **194**. This resistor comprises an insulation resistance (R_{IR}) **202**, which is the insulation resistance of the MLCC chip capacitor **140'**. In a high-quality capacitor, this insulation resistance value tends to be in the hundreds of megohms or higher and does not significantly contribute to the capacitor ESR, therefore, for the purpose herein, can be ignored as part of the filter capacitor equivalent circuit model. The (R_{IR}) also has negligible effect on capacitor high frequency performance. For three-terminal or physically small MLCC chip capacitors, the equivalent series inductance (ESL) **204** shown in FIG. **25** can also be ignored because inductive reactance is very low at low frequencies and filter capacitor inductance can be considered negligible at high frequencies. Accordingly, the ESR **198** of the AIMD diverter MLCC chip capacitor **140'** of FIG. **26** is the sum of the dielectric loss tangent resistance (R_{DL}) **192**, the total ohmic loss (R_o) **200** and any losses due to skin effect (R_s), which is not labelled in FIG. **26**. Specifically, regarding skin effect, at low frequencies, skin effect is negligible, and for physically small MLCC chip capacitors and feedthrough filter capacitors, skin effect does not really play a role until one gets to very high frequencies, for example, above 200 MHz. It is noted, therefore, that for the MRI RF frequencies 21.28 MHz (0.5 T), 64 MHz (1.5 T), and 128 MHz (3 T), skin effect (Rs) is negligible and may be ignored, which is why FIG. **26** does not label (R_s). Hence, assuming that the filter capacitor has good metallization, essentially oxide-free connection to the ferrule and good electrical attachment materials, then the total ohmic loss (R_o) **200** is completely dominated by the electrode resistance (R_e) **190**. Thus, for the purpose of the present invention, at MRI RF frequencies the ESR **198** of the filter capacitor is generally equal to the dielectric loss tangent resistance (R_{DL}) **192** plus the electrode resistance (R_e) **190**. Both of these parameters, (R_{DL}) and (R_e), must be carefully controlled for the high-power RF diverter MLCC chip capacitor **140'** of the present invention.

In summary, it has been shown that dielectric loss is a frequency variable and that, for at least the MRI RF-pulse frequencies 21.28 MHz (0.5 T), 64 MHz (1.5 T), and 128 MHz (3 T), the dielectric loss for a low k EIA Class I ceramic filter capacitor drops to a very low value (essentially zero) such that the ESR **198** of a diverter low k filter capacitor is primarily determined by the total resistance of its electrode plates.

FIG. **27** is a more detailed illustration of the dielectric loss in ohms of a relatively low k ceramic filter capacitor. One can see, at low frequencies, the dielectric loss in ohms can be over 100 ohms or even much greater. However, as one increases in frequency, one can see that the dielectric loss drops and is nearly zero at 64 MHz (the RF-pulse frequency of a 1.5 T MRI scanner).

FIG. **28** shows a U-shaped composite curve. The composite curve is the summation of filter capacitor ohmic loss, which includes the total resistance of capacitor electrodes, capacitor metallization, electrical attachment materials, and electrical connection. As one can see, and ignoring skin effect, the conductor ohmic loss for the filter capacitor is relatively constant from low frequency all the way to very high frequencies. For an EIA Class I dielectric, the filter capacitor dielectric loss (marked with small squares) is a very high value at low frequency, and then drops to near zero at MRI RF frequencies such as 64 MHz and 128 MHz. Skin effect is also shown, which is an ohmic loss for two-terminal type filter capacitors. The total ESR is the solid line, which is the summation of the capacitor dielectric loss, the capacitor conductor ohmic loss and skin effect. The present invention is directed to make sure the center of this total ESR U-shaped curve includes the range of MRI RF-pulse frequencies at the near zero value.

FIG. **29** is a table showing an example of losses (which are measured losses) for a prior art 2,000-picofarad X7R (2,500 k) feedthrough filter capacitor. One can see that at the 1 kHz frequency, the X7R capacitor dissipation factor DF loss is about 1591.55 ohms and the ohmic loss is 0.432 ohms. When the dissipation factor DF loss is added to the ohmic loss, the X7R capacitor equivalent series resistance (ESR) is about 1591.98 ohms. Even at 1 MHz frequency, the X7R capacitor measures a dissipation factor DF loss of about 1.59 ohms, which, when added to the ohmic loss of 0.432 ohms, yields an ESR of about 2.024 ohms. It becomes apparent that at both the 1 kHz and 1 MHz frequencies the X7R capacitor dissipation factor DF losses dominate the ohmic losses. As a result, the ohmic loss is essentially hidden or indistinguishable due to such a significantly higher DF loss at these frequencies. It is not until a frequency of at least 10 MHz that the DF loss no longer dominates the capacitor ESR measurement and the ohmic loss of the X7R filter capacitor becomes discernable. This is very important in understanding a filter capacitor's real losses. As shown by FIG. **29**, at a testing frequency greater than 10 MHz, the X7R filter capacitor has an ESR ranging from about 0.59 to about 0.44 ohms, which is still significant. Referring once again to the curve of FIG. **28**, an ESR ranging from about 0.59 to about 0.44 ohms at frequencies from 10 MHz to 500 MHz substantially raises the center of the U-shaped curve away from the near zero ESR value desirable for effectively diverting RF energy induced in AIMD leads at MRI RF-pulse frequencies. Hence, as one can see, despite the specifications of MIL-STD-202 and MIL-STD-220 among others, measuring an AIMD filter capacitor's losses at 1 kHz and 1 MHz is not a useful way to analyze a filter capacitor's actual losses at MRI RF-pulse frequencies. In summary, to properly assess filter capacitor losses at MRI RF-pulse frequencies, one needs to analyze loss measurements in the range of 10 MHz to 500 MHz because at frequencies above

10 MHz the dissipation factor drops and the ohmic losses of the capacitor become visible making it easier to distinguish between acceptable and unacceptable capacitor high frequency performance.

FIG. 30 dramatically illustrates the difference in capacitor performance when one uses an EIA Class I dielectric, such as C0G (NP0), which has a dielectric constant of less than 200. Because of this low dielectric constant, a high number of electrode plates of the capacitor is necessary to achieve the filtering performance required for AIMDs. The high number of electrode plates has the effect of greatly reducing the capacitor's ohmic losses. In addition, EIA Class I dielectrics have a lower dissipation factor, particularly at high frequency. Comparing 100 MHz frequency measurements of the X7R capacitor of FIG. 29 and the C0G (NP0) capacitor of FIG. 30, one can see that the ESR of the C0G (NP0) capacitor is about 0.201 ohms vs. an ESR of about 0.45 of the X7R capacitor. The ESR of the C0G (NP0) capacitor is reduced by more than 50% the ESR of the X7R capacitor, which, for AIMD applications, is considered a significant ESR reduction. By also increasing the number of electrode plates (see capacitors 210, 210' in FIGS. 32, 34-36), the ESR of the C0G (NP0) capacitor may be further reduced to below 0.1 ohms. Thus, the dielectric material C0G (NP0) and the increased number of electrode plates of the AIMD diverter feedthrough filter capacitor of the present application substantially lowers capacitor ESR and will significantly reduce heat generation in said AIMD diverter feedthrough filter capacitor (for example, the feedthrough filter capacitor 210, 210' or even 210" and 210''' of the present application).

Further regarding the present invention, the inventors have contemplated using a dielectric material having dielectric constant k<1,000 for filter capacitors. The inventors have developed a mid k dielectric filter capacitor for making filter capacitors for use in AIMDs (for example, the feedthrough filter capacitor 210, 210', 210" and 210''' of the present application). The mid k dielectric filter capacitor is on the order of 500, comprising a dielectric constant of approximately 500 to as much as 700. The inventors used various dopants and firing conditions, such that, the new mid k dielectric provides an ohmic loss (R_o) of less than 100 milliohms at frequencies from 10 MHz to 100 MHz. In some embodiments, the inventors have achieved resistance losses on the order of 50 milliohms. Since the dielectric loss at the 10 MHz to 100 MHz frequency range is nearly zero, this means that the total ESR of the new mid k capacitors essentially only reflect the ohmic loss (Ro), thus are the order of 50 milliohms to as much as 100 milliohms at MRI RF-pulse frequencies. As, for example, a 1.5 Tesla MR scanner has an RF-pulse frequency of 64 MHz, it is very important to have low resistances in order to minimize capacitor heating as the AIMD diverter capacitor diverts the RF-pulse frequency during an MRI scan. This is accomplished by the capacitors of the present application having a dielectric material of a dielectric constant k<1,000.

FIG. 31 is an equivalent series resistance (ESR) versus frequency graph from a frequency sweep done on a low k feedthrough filter capacitor 210 of the present application using an Agilent E4991A materials analyzer. At a start frequency of 1 MHz (curve 136), one can see that the ESR of the low k feedthrough filter capacitor 210 is on the order of 6 ohms, which is considered very high. However, by the time one reaches about 21.28 MHz (the frequency of a 0.5 T MRI scanner), the ESR of the low k feedthrough filter capacitor comprising an EIA Class I dielectric begins to flatten out. As dielectric loss at about the 10 MHz to 100 MHz frequency range is nearly zero, the only loss reflected by curve 136 is the ohmic loss of the low k feedthrough filter capacitor 210, which at 100 MHz is only 200 milliohms. It is noted that the ESR of said capacitor is also 200 milliohms at the RF-pulse frequencies for a 1.5 Tesla scanner (64 MHz) and a 3 Tesla scanner (128 MHz).

Since the 1960s, as previously mentioned, it has been a common practice in the capacitor industry to measure capacitance and dissipation factor at 1 kHz. The dissipation factor is usually defined as a percentage, for example, 2.5% maximum. What this means is that the dielectric loss resistance can be no more than 2.5% of the capacitive reactance at a certain frequency (which characteristically has been 1 kHz). As an example, if the capacitive reactance for a particular capacitor is 80,000 ohms at 1 kHz with a 2% dissipation factor this equates to 1,600 ohms of resistance at the 1 kHz frequency. Referring once again to FIG. 28, it is noted that the dielectric loss essentially goes to about zero at high frequency. For typical low k dielectric constant EIA Class 1 ceramic capacitors, frequencies above 10-20 MHz is sufficiently high so that the dielectric loss is no longer a dominating factor in the capacitor ESR measurement. Hence, as the ESR of a capacitor varies with the capacitance value, the number of electrode plates, and the length and width of the electrode plates, a wide range of "normal" ESR readings can be obtained for many types of capacitors by using the teachings of the present application (see the filter feedthrough capacitors 210, 210', 210" and 2101. For example, one particular capacitor may have a normal ESR reading of 0.05 ohms while another capacitor design may have a normal ESR as much as 10 ohms.

Referring once again to FIG. 31, one can see curve 137, which represents the inventors new mid k dielectric (k on the order of 500 to 700). As can be seen, the new mid k dielectric, in general, yields filter capacitors that have a total equivalent series resistance of less than 100 milliohms between 10 MHz and 100 MHz frequencies. There are even certain design configurations with a sufficient number of electrode plates where the capacitor's ESR is between 10 and 50 milliohms in the 10 MHz to 100 MHz frequency range.

Regarding number of electrode plates, maximization of the number of electrode plates in order to reduce the electrode resistance (R_e) of an MLCC chip capacitor becomes paramount (shown in the low k MLCC chip capacitor 210 of FIG. 32 and feedthrough filter capacitor 210' in FIG. 34). In general, in order to increase the number of electrode plates, the effective capacitance area (ECA) can be minimized and the dielectric constant k lowered so that one ends up with a relatively high number of electrode plates. One might ask, why doesn't one simply make the electrode plates much thicker in order to decrease their resistance? It is true that making the electrode plates very thick reduces their resistance, however, there is an undesirable consequence. The capacitor is longer monolithic and is simply like a sandwich or somewhat like a deck of cards that is ready to come apart at the first thermal shock or piezoelectric effect. It is a basic tenet of ceramic engineering that electrodes be thin enough, and contain enough ceramic powder such that when sintered, the ceramic capacitor structure becomes truly monolithic. This leaves the designer with only a few effective ways to control the capacitor's ESR. For a given geometry, which is usually dictated by the AIMD design, there are very few degrees of freedom in the length, width and geometry of capacitor electrode plates. Accordingly, in the present invention, maximizing the number of electrode plates becomes a key design factor. This

goes hand in hand with the dielectric constant k of the capacitor. In other words, reducing the dielectric constant of a capacitor dielectric means that the number of capacitor electrode plates must increase to achieve the same capacitance value as a capacitor using a dielectric material having a high dielectric constant. The increase in the number of electrode plates naturally reduces the ESR of the capacitor and increases the ability of the capacitor to handle high levels of RF current. Another reason to keep the ESR of the diverter filter capacitor **210, 210'** extremely low is so the filter capacitor does not overheat while diverting high levels of RF currents to the housing **124** of the AIMD **100**, the AIMD housing being an energy dissipating surface (EDS). In the present application, feedthrough filter capacitors and MLCC chip capacitors can act as high-power RF energy diverters. Energy diverters using an energy dissipation surface (such as a ferrule **134** or an AIMD housing **124**) are more thoroughly described in U.S. Pat. Nos. 8,219,208 and 7,751,903, the contents of which are fully incorporated herein by these references. In a diverter filter capacitor, the RF currents are literally conducted through the electrode plates **212, 214** of the filter capacitor **210, 210'** and hence through the electrode plate resistance (Re) **190**. Electrode plate resistance (R_e) **190** is the sum total of the resistance of all of the electrode plates **212, 214** acting in parallel. If the electrode plate resistance (Re) **190** is high, then there is a tremendous amount of I^2R power loss that occurs and the filter capacitor **210, 210'** rapidly gets very hot and perhaps destroys itself and/or the surrounding electrical connections or materials. Another reason to keep the ESR **198** of the filter capacitor **210, 210'** relatively low is so that the ESR represents a very low impedance Z at the MRI RF-pulse frequency. This will increase ability of the filter capacitor **210, 210'** to draw energy from the implanted lead **110** and divert the energy to the energy dissipating surface of the AIMD housing **124**. If the filter capacitor represented too high of an impedance, which reduces the current, but also means that more energy is undesirably left in the implanted lead **110**. Lowering the impedance Z of the diverter filter capacitor **210, 210'** also means that it is a better EMI filter by offering increased attenuation at the MRI RF-pulse frequency.

Even so, it is most important to keep the overall resistance **190** of the electrode plates extremely low (in other words, extremely low ESR) so that overheating of the primary filter capacitor **210** itself is prevented. It has been demonstrated that overheating of the filter capacitor causes the adjacent AIMD housing **124** to also overheat. This is highly undesirable in a human incision pocket. Typically, the AIMD is placed under the skin, under the fat or even under a muscle. There are various FDA and CEM42 Standards that limit the amount of heat introduced to various types of body tissue. In general, the amount of heating is limited to 4° C. (that can vary with body tissue). For example, for a deep brain stimulator, a subdural implanted AIMD must have a much lower temperature rise due to the extreme thermal sensitivity of brain matter. This is in contrast to a pectoral pocket created for cardiac pacemaker or ICD, which represents less thermally sensitive tissues and fats. In any event, it is a major feature of the embodiments herein to prevent the overheating of the primary filter capacitor in order to minimize or eliminate heating of the AIMD housing **124**.

In general, the filter capacitor **210, 210'** of the present invention may have at least 10 electrode plates. The filter capacitor comprises a dielectric material having a k up to 1,000. It is contemplated that the filter capacitor **210, 210'** may comprise an intermediate dielectric constant (mid k) of say 400, 500 or even 600. A mid k dielectric material makes it possible to design a capacitor with less than 10 electrode plates, for example, 5 electrode plates (depending upon their length and width) and still have a low enough ESR in accordance with the present invention (meaning, 5 active electrode plates with **5** ground electrode plates). Alternatively, the number of electrode plates can be as high as 20, 40 or even 100 or more; nonetheless, the critical parameter is that the equivalent series resistance (ESR) of the filter capacitor never exceeds 2 ohms at the MRI RF-pulse frequency. In some embodiments, the ESR can be <0.5 ohm. In some embodiments, the ESR is 0.1 ohm.

FIG. **32** illustrates a cross-section of a multi-layer ceramic capacitor MLCC chip capacitor **210** of the present invention, which is similar to the prior art MLCC chip capacitor **140'** illustrated in FIGS. **14, 19** and **20**, except that the number of electrode plates in the MLCC chip capacitor of FIG. **32** is substantially increased to minimize ESR. As previously disclosed, the number of electrode plates is a key factor for reducing capacitor ESR. Both the active electrode plates **212** and the ground electrode plates **214** are substantially increased in order to reduce the ESR **198** of the MLCC chip capacitor **210** to less than 2 ohms at the MRI RF-pulse frequency. In an embodiment, the ESR **198** of the MLCC chip capacitor **210** is less than 1 ohm. In addition to the increased number of electrode plates, the MLCC chip capacitor **210** comprises a low k dielectric material (k<1, 000) so that the capacitance value is not too high. In an embodiment, the dielectric material is an EIA Class I capacitor such as NP0.

Referring once again to FIG. **32**, one can see that the active electrode plates **212** (on the left-hand side) and the ground electrode plates **214** (on the right-hand side) are stacked in an interleaved relation. An electrical attachment material **152** connects the active capacitor metallization **164** to the terminal pin **142** on the left-hand side and the ground capacitor metallization **166** to the ferrule **134** of a hermetic feedthrough **132** on the right-hand side. In general, the electrical connection material **152** is highly electrically conductive, but not necessarily highly thermally-conductive. In summary, the MLCC chip capacitor **210** of FIG. **32** is based on an EIA Class I dielectric, which means its dielectric constant is relatively low and its temperature coefficient, in accordance with standard ANSI/EIA-198-1, published Oct. 29, 2002, Table 2, namely, a permissible capacitance change from 25° C. (ppm/° C.) for Class I ceramic dielectrics. Thus, the maximum allowable capacitance change varies from +400 to −7112 parts per million per degree centigrade. As previously mentioned, an embodiment comprises the C0G dielectric, which is also commonly referred to as NP0.

FIG. **33** is an equation showing the effect of the parallel plate resistances. FIG. **33** gives the equation for the total resistance of the electrode plates (R_{et}) of the MLCC chip capacitor being the summation of all parallel electrode plates **212, 214** ("n" electrode plates) of the MLCC chip capacitor.

FIG. **34** is very similar to the cross-section of the quad polar feedthrough filter capacitor previously described in FIGS. **9-10**, except that the number of electrode plates **212, 214** have been increased in accordance with the present invention such that the FIG. **34** quad polar diverter feedthrough filter capacitor **210'** has a high frequency ESR **198** less than 2 ohms. Referring once again to FIG. **34**, one can see that the outside diameter ground capacitor metallization **166** is attached to a gold pocket-pad area **158** of ferrule **134** using a conductive material **152**. All of these connections, when properly done, have negligible resistance. Accordingly, the ESR **198** of the feedthrough filter capacitor **210'** at high frequency comprises the electrode resistance (R_e) **190**

of the ground electrode plates **214** and the electrode resistance (R_{e_f}) **190'** of the active electrode plates **212** all acting in parallel. As previously stated, for EIA Class I dielectrics, the dielectric loss tangent resistance **192** of the feedthrough filter capacitor **210'** can be ignored at MRI RF-pulse frequencies since said dielectric loss tangent resistance becomes negligible at RF-pulse frequencies. Also, for a feedthrough filter capacitor geometry, skin effect (R_s) is also negligible. Referring once again to FIGS. **7-8**, one can see a rectangular quad polar capacitor that is similarly attached to a gold pocket-pad area **158**.

FIG. **35** is taken from section **35-35** of FIG. **34** and illustrates a doubling (dual electrode plates) of the active electrode plates **212** and the ground electrode plates **214** of the feedthrough filter capacitor **210'**. Doubling the electrode plates **212**, **214** is very effective since both electrode plates are still exposed to the internal electric fields of the feedthrough filter capacitor; therefore, both the active and the ground electrode plates, each having doubled plates, will more effectively support electrode plate displacement current flow (RF currents). Dual electrode plate capacitor designs greatly increase the number of electrode plates of a capacitor, which, as shown by the equation of FIG. **33**, significantly reduces the overall total electrode plate resistance (R_{et}). Dual electrodes are disclosed in U.S. Pat. No. 5,978,204 to Stevenson et al., the content of which is fully incorporated herein by this reference. In the '204 patent, the dual electrodes were utilized to facilitate high pulse currents, for example, in an implantable defibrillator application. Dual electrodes as applied to the present application are very useful in driving down electrode resistance (R_e), thereby driving down the high frequency ESR **198** of the feedthrough filter capacitor **210'** while also enhancing conduction of RF energy and/or heat **218** out of the feedthrough filter capacitor **210'** during exposure to high power MRI RF-pulse environments.

FIG. **36** is very similar to FIG. **35**, except in this case only the ground electrode plates **214** have been doubled. Increasing the number of ground plates **214** is particularly efficient in the removal of RF energy and/or heat. As shown, the ground plates **214** are utilized to conduct heat away from the diverter feedthrough filter capacitor **210'**, directing the heat through the ferrule **134** of the hermetic feedthrough **132** to the housing **124** of the AIMD **100**, the housing **124** having a relatively large surface area for heat dissipation. The relatively large surface area of the housing **124** of the AIMD **100** means that a great deal of RF energy and/or heat **218** can be dissipated without concentrating such energy in a small location, which can lead to a very high temperature rise and possibly cause damage to surrounding body tissue.

FIG. **37** illustrates a family of lowpass filters **260** that all incorporate diverter capacitors of the present invention. As can be seen, these lowpass filters **260** incorporate a variety of capacitor designs ranging from a simple MLCC chip capacitor "C" to a three-terminal "feedthrough capacitor-FTC". These diverter capacitors (generally labelled **210** for simplicity) can be combined in various ways with inductors to form "L", "reverse L", "T", "Pi" (π), "LL", "reverse LL" or "n" element lowpass filters. In other words, as illustrated in FIG. **37**, any of the high-power RF handling diverter capacitors of the present application can be combined with any of the lowpass filter circuits of an AIMD for the purpose of protecting the AIMD electronics from EMI, while at the same time pulling MRI induced RF energy or heat from an implanted lead.

FIG. **38** is similar to FIG. **83** of U.S. Pat. No. 9,014,808, the content of which is fully incorporated herein by this

reference. The electrical schematic of FIG. **38** represents the simplest form of the lowpass filters of FIG. **37**. Represented is a lead in connection with an AIMD hermetic feedthrough **132**, which is in connection with a lowpass filter **260**, which can comprise any diverter capacitor of FIG. **37**. FIG. **38** illustrates the general lowpass filter **260** being an exemplary feedthrough filter capacitor **210'** which is connected in series with a bandstop filter **258**, which is, in turn, connected with an L-C trap filter **262** disposed between the circuit trace or leadwire and the AIMD housing **124**.

FIG. **39** shows a dual chamber bipolar cardiac pacemaker **100C** with leads implanted into the right atrium and right ventricle of the heart **112**. As shown, header block **138** comprises industry standard IS-1 connectors **126a**, **128a**, **126b**, **128b**. MRI energy is shown being induced on the implanted leads **110** and **110'**. As this energy enters the pacemaker housing **124**, it encounters diverter capacitor **210'**. The diverter capacitor **210'** is designed to dissipate high RF energy or heat in accordance with the present invention. Accordingly, diverter capacitor **210'** has a low dielectric loss at high frequency and also very low high frequency ESR. In this case, there is a secondary row of MLCC chip capacitors **210a** through **210d** that are mounted on the AIMD circuit board **130** at a location distant from the primary diverter capacitor **210'**. In this case, the primary diverter capacitor **210'** can have a lower capacitance value with the rest of the capacitance comprising either circuit board mounted capacitors **210a** through **210d** or other similar electrical components. As illustrated, the AIMD circuit board **130** comprises a ground circuit trace **182** that is connected through a low impedance RF conductor, which in FIG. **39** is an RF grounding strap **264**, that conducts the RF energy or heat to the AIMD housing **124**. This low impedance RF grounding strap **264** is important to conducting MRI RF currents efficiently to the housing **124** of the AIMD **100C**. In order to spread out heat, multiple low impedance RF conductors can be used (not shown) of various shapes and configurations, and in any shape and configuration combination. A major advantage of the embodiment shown in FIG. **39** is that by spreading out the filtering function, RF energy/heat or MRI RF energy induced heat is dissipated or spread out over much larger areas. This avoids hot spots on the AIMD housing **124**. Referring once again to FIG. **39**, it is appreciated that if the capacitance value of the primary filter capacitor **210'** (which can be a feedthrough capacitor, an MLCC chip capacitor, an X2Y attenuator, a flat-through capacitor or combinations thereof) is sufficiently large, then the MLCC chip capacitors **210** shown on the circuit board **130** are not necessary. Alternatively, if the circuit board **130** was placed immediately adjacent to the ferrule **134**, then it is possible to eliminate the feedthrough capacitor **210'** and instead have an MLCC chip capacitor, an X2Y attenuator, a flat-through capacitor or combinations thereof each associated with one of the quad polar leads to act as high frequency RF energy diverters. In summary, referring back to FIG. **39**, it is appreciated that one can have a primary filter capacitor **210'** that is backed up by one or more onboard chip capacitors **210** or only a feedthrough capacitor **210** or only one or more board-mounted chip capacitors, for example, MLCC chip capacitors **210a** through **210d**.

FIG. **39A** is the electrical schematic of one of the leadwire circuits **136a** of the cardiac pacemaker **100C** of FIG. **39**. The first low ESR feedthrough filter capacitor **210'** is shown in parallel with a two-terminal capacitor **210a**. It is appreciated that all four of the quad polar leads **136a** through **136d** have the same electrical schematic parallel representation.

Referring once again to FIG. **39**, it is noted that at least two of the leadwires **136***a* through **136***d* extend through the hermetic feedthrough **132** in non-conductive relationship with the ferrule **134** and then extending through respective bores of the feedthrough filter capacitor **210'**. These leadwires **136***a* through **136***d* then extend to the device side, which is inside the AIMD housing **124**, and each are electrically connected to either a via hole or circuit trace land of the AIMD circuit board **130**. Each via hole or circuit trace land on circuit board **130** are electrically connected to a capacitor metallization of one of the MLCCs **210***a* through **210***d* by leadwires **142***a* through **142***d*. For the purposes of this invention, we will refer to the internal electrode plates of the MLCC chip capacitors **210** as having ground electrode plates and active electrode plates. The ground electrode plates are connected to the MLCC chip capacitor's end termination and are therefore electrically connected to the ground circuit trace **182**. The capacitor's active electrode plates are electrically connected to at least two leadwires of the leadwires **142***a* through **142***d*. It is appreciated by those skilled in the art that circuit board **130** can be an alumina ceramic board, a single layer board, a multi-layer board, fiberglass or FR4 or any number of materials of which circuit boards are made. It will also be appreciated that a connection from the active side of the capacitors **210** can be accomplished by a flex cable (not shown). In such an embodiment, the flex cable replaces the leadwires **142***a* through **142***d* on the device side (the inside or inboard side) of the AIMD housing and the flex cable connects to shortened leadwires adjacent the feedthrough filter capacitor **210'**. The use of a flex cable greatly simplifies and facilitates the assembly of the AIMD internal circuits. It should also be noted that the ground circuit traces **182** and the embedded circuit traces **178** of circuit board **130** (and other circuit traces not shown) can be made from a variety of materials. Since these are inside the hermetically sealed and biocompatible AIMD housing **124**, the circuit traces need not be biocompatible themselves. In fact, they can be made of copper, silver, platinum or any other highly conductive material. In an alternative embodiment (FIG. **39**B), the chip capacitors **210***a* through **210***d* of the circuit board **130** of FIG. **39** can instead be mounted directly to the flex cable **171** of FIG. **39**B.

FIG. **39**B illustrates a unipolar hermetic feedthrough consisting of a ferrule **134**, an alumina insulator **156** and a leadwire **136**, wherein, the leadwire is labelled **136** on the body fluid side and the same leadwire is labelled **142** on the device side (or inboard side). Shown is a flex cable **171**, wherein a first circuit trace (an active circuit trace **143**) is connected to the hermetic device side terminal pin **142** of the feedthrough. There is also a second circuit trace (a ground circuit trace **182**) which is connected to the ferrule **134**, which is the ground connection (the potential of the ferrule **134** is the ground potential). Importantly, the ferrule **134** is welded to the AIMD housing **124**. The MLCC chip capacitor **210**, which has a k<1,000 in accordance with the present invention, is shown electrically connected between the ground circuit trace **182** and the active circuit trace **143** using an electrically conductive material **152**. Electrical connection material **152** can be a solder, a thermal-setting conductive adhesive, a thermal setting conductive epoxy, a thermal setting conductive polymer or similar such conductive material.

Referring once again to FIG. **39**, one can see that the MLCC chip capacitors **210***a* through **210***d* are a considerable distance from the point of leadwire ingress of the device side terminal pins **142***a* through **142***d* of the hermetic

feedthrough **132**. The embodiment shown in FIG. **39**B positions the MLCC chip capacitor **210** closer to the point of leadwire ingress of the device side terminal pin **142** in comparison with the positioning of MLCC chip capacitors **210***a* through **210***d* to the ingress of the device side terminal pins **142***a* through **142***d* of FIG. **39**. The ingress of the device side terminal pin **142** is also the point of ingress of undesirable EMI signals that may be picked up on an implanted lead. Having the MLCC chip capacitors as close as possible to the ingress of the device side terminal pin **142** of the hermetic feedthrough **132** is desirable since at this ingress point the inductance or inductive loop inside the device is reduced. This helps to prevent the so-called "genie-in-the-bottle" effect wherein, once EMI is inside the AIMD housing, it can cross-couple, re-radiate or couple through antenna action to sensitive electronic AIMD circuits thereby causing disruption in device therapy delivery. At MRI RF-pulse frequencies this is not a particular concern since, for a 1.5 T scanner, the RF-pulse frequency is 64 MHz. The wavelength of a 64 MHz signal is so long that it really does not effectively re-radiate once inside an AIMD housing. However, if the MRI filter MLCC chip capacitor **210** is also to be used as a broadband lowpass filter, for example, where it must filter out very high frequency signals above 1 GHz, such as those signals from cellular telephones, then it is desirable to have the MLCC chip capacitor **210** as close as possible to the point of leadwire ingress. Using an MLCC chip capacitor for both diverting MRI RF-pulse frequencies and also as a broadband lowpass filter means that one desirably places the MLCC chip capacitor as close as possible to the point of leadwire ingress. This is specifically shown in FIG. **19** with MLCC chip capacitors **140'**, which of course, can be MLCC chip capacitors **210** in accordance with the present invention. One is also referred to FIG. **54**, which places the MLCC chip capacitors **210***a* and **210***b* directly at the point of leadwire ingress into an AIMD housing, where the MLCC chip capacitors **210***a* and **210***b* are each connected to a terminal pin (**142***a* and **142***b* respectively) and to the gold braze **152'** of the ferrule **134**, thereby providing the lowest impedance connection possible. Mounting MLCC chip capacitors directly at the point of leadwire ingress is further taught by U.S. Pat. Nos. 5,650,759 and 5,896,267, the contents of which are fully incorporated herein by these references.

FIG. **39**C illustrates the electrical schematic of FIG. **39**B.

FIG. **40** illustrates an alternative embodiment to FIG. **39**. Similar to FIG. **39**, an AIMD circuit board and MLCC chip capacitors **210***a* through **210***d* are shown; however, in the embodiment of FIG. **40**, the ground circuit trace **182** does not require an RF conductor such as the RF grounding strap **264** to the AIMD housing. Instead, a shielded conduit assembly **266** is attached to the ferrule of the hermetic terminal (not shown). This shielded conduit **266** is grounded with a strap **268** which is connected to the ground circuit trace **182**. This type of EMI shielded conduit assembly is more thoroughly described in U.S. Pat. No. 8,095,224 to Truex et al., the content of which is fully incorporated herein by this reference.

FIG. **41** shows a cross-sectional view of a flexible circuit board **270**, which can also be a flex cable. The flexible circuit board **270** is attached on the left-hand side using a ball grid array (BGA) type attachment **151**. BGA attachment **151** is further connected to a terminal pin **142** that passes through a hermetic feedthrough **132** (not shown) of an AIMD. These types of flexible circuit boards, circuit traces or substrates are also described in the incorporated U.S. Pat. No. 8,095,224 to Truex et al.

FIG. 42 shows a sectional view generally taken from section 42-42 of FIG. 41 and shows the conductive circuit traces 178a through 178d.

FIG. 43 illustrates a sectional view generally taken from section 43-43 of FIG. 41 and shows an optional embodiment wherein a ground circuit trace 182 is a ground circuit shield, the ground circuit trace surrounding the four circuit traces 178a through 178d.

FIG. 44 is a sectional view taken generally from section 44-44 of FIG. 41 and illustrates shield layers 272a, 272b. These shield layers 272a, 272b are designed to surround each of the circuit trace layers 178 as previously described in FIG. 42 or 43. These shields 272a, 272b are not absolutely required, but greatly assist in preventing re-radiation of electromagnetic interference inside of the AIMD housing 124. This re-radiation of EMI can be very dangerous as it can couple to sensitive AIMD circuits and disrupt the proper functioning of the AIMD.

FIG. 45 illustrates an embodiment in which the circuit traces 178a through 178d of FIGS. 41 through 44 are connected to a circuit board 270 or a circuit board substrate. Electrical attachments 274 are made to active circuit traces and in turn to a multi-element diverter flat-through capacitor 210″. This three-terminal flat-through capacitor 210″ is very similar to flat-through capacitor 140″ previously described in FIGS. 17 and 18 except that the flat-through capacitor of FIG. 45 has four capacitors embedded in a single structure. Flat-through capacitor 210″ may replace the individual MLCC chip capacitors 210a through 210d of FIGS. 39 and 40.

FIG. 46 shows a top view of the diverter flat-through capacitor 210″ of FIG. 45.

FIG. 47 is a sectional view taken generally from section 47-47 of FIG. 45 and shows the active electrode plates 212 of the flat-through capacitor 210″ of FIG. 45.

FIG. 48 is a sectional view taken generally from section 48-48 of FIG. 45 and shows the ground electrode plate 214 of the flat-through capacitor 210″ of FIG. 45.

Accordingly, regarding the foregoing, it is appreciated that the present application addresses the problems created when an MRI radio frequency (RF) pulse field couples to an implanted lead in such a way that electromagnetic forces (EMFs), voltages and current are induced in said implanted lead. The amount of RF energy that is induced is related to a number of complex factors, but in general, is dependent upon the local electric field that is tangent to the implanted lead and the integral electric field strength along the implanted lead. In certain situations, these EMFs can cause currents to flow into the distal electrodes of the implanted lead or at the point at which the electrode interfaces with body tissue. It has been documented that, when RF current becomes excessive, overheating of the implanted lead or its associated electrodes in contact with body tissue can occur. Consequently, overheating of the body tissue interfacing with the implanted lead electrodes can also occur, and subsequently potentially cause substantial body tissue damage. There have been cases of damage to cardiac tissue due to overheated electrodes, wherein the damage caused resulted in loss of capture of cardiac pacemaking pulses. Furthermore, with respect to neurostimulators, neurological tissue damage severe enough to result in brain damage or multiple limb amputations have also been documented.

The present invention relates generally to methods and apparatus for redirecting RF energy to locations other than the distal tip electrode-to-tissue interface. In addition, the present invention provides electromagnetic interference (EMI) protection to sensitive active implantable medical

device (AIMD) electronics. The redirection of this RF energy is generally achieved by the use of frequency selective devices, such as inductors, capacitors and filtered networks. As described in U.S. Pat. No. 7,689,288, to Stevenson et al., the content of which is fully incorporated herein by this reference, filtered energy dissipation networks can range from a single capacitor, such as a feedthrough capacitor, to more complex filters that may include L-C traps and/or L-C bandstop filters co-operating in various ways with C, L, Pi (π), T or n-element lowpass filters. In general, this is accomplished through frequency selective lowpass filters or series resonant L-C trap filters, wherein the RF energy can be redirected to another surface or is converted to heat. In all of the above described frequency selective networks, it is the capacitor(s) (co-operating with other circuit elements) which diverts RF energy from an implantable lead to the conductive housing 124 of an AIMD. The relatively large surface area of the AIMD housing 124 acts as an energy dissipating surface (EDS) wherein a significant amount of the MRI energy can be harmlessly dissipated without significant temperature rise. However, the lowpass filter, also known as diverter capacitor elements, must be designed to handle a very high amount of RF current and power. Accordingly, the capacitor's internal resistive or real losses known as equivalent series resistance (ESR) must be kept quite low. The present application is directed to various embodiments of MRI diverter capacitor designs that minimize the diverter capacitor's equivalent series resistance (ESR). In addition, the capacitor is also designed to direct heat to relatively large surface area heat dissipation surfaces, thereby creating an efficient heat removal system. These high RF power/low ESR diverter capacitors are an important feature of the filter network of the present invention for diverting induced RF energy from an implanted lead to an energy dissipating surface, particularly a conductive housing 124 of an AIMD.

While these implantable lead systems are generally associated with AIMDs, such as cardiac pacemakers, cardioverter defibrillators, neurostimulators and the like, the present invention can also be incorporated into external devices, such as external pacemakers, externally worn neurostimulators (such as pain control spinal cord stimulators), catheters, probes, temporary external devices, temporarily implanted active devices and the like. It will be shown that for a given geometry constraint, a preferred means of reducing the diverter capacitor's ESR is to select the most ideal dielectric type so that its dielectric loss tangent (dielectric losses) is insignificant at the MRI RF-pulse frequency (ies). Of particular importance in the present invention is selection of a capacitor dielectric with the proper dielectric constant (k) value. The preferred capacitor dielectric will have a k of a sufficiently low value to thereby increase the number of active and ground electrode plates in the capacitor. This design feature dramatically reduces the ohmic losses in the capacitor at high frequency. Therefore, to accomplish a relatively high electrode plate count, a low k capacitor dielectric is used. A non-limiting example of one such dielectric material is an EIA standard, Class I dielectric material, C0G, which is also known as NP0 (negative-positive-zero)/(refer to EIA Standard ANSI/EIA-198-1-F-2002). Some low k capacitors may have a dielectric material having a k<1,000. Alternatively, some low k capacitors may have a dielectric material having a mid k value, such as 400 to 700. Additionally, some low k capacitors may have a dielectric material having a k<200. Some low k capacitors may also have a dielectric material having a k<100.

In general, at first glance, using an EIA Class I dielectric is counterintuitive. For example, consider a typical X7R MLCC chip capacitor dielectric, with a dielectric constant of around 2,500. With such a high efficiency dielectric material, which has a relatively high dielectric constant, it is possible to build, for example, a 1,000 picofarad filter capacitor with two to four electrode plates. Now consider using an EIA Class 1 C0G dielectric, wherein the dielectric constant is less than 100. A typical capacitor comprising the C0G dielectric material generally requires greater than 20 or even 40 electrode plates to achieve the same capacitance value as the X7R capacitor. The benefit of incorporating a C0G dielectric material within the capacitor design is generally a reduction of the capacitor's ESR at MRI RF-pulse frequencies. If designed properly, for example, designing the capacitor with an appropriate number of electrode plates, the RF energy heat that is produced when positioned within an MRI scanner can be significantly reduced such that the heat resulting from RF energy does not pose harm to biological tissue.

Hence, as disclosed above, one purpose of the low ESR diverter capacitor is to draw MRI induced RF energy out of the implanted lead and redirect said RF energy to the AIMD housing. Such low ESR capacitors have the effect of reducing the RF energy that reaches the distal tip electrode or its interface with body tissue. By redirecting said RF energy to locations at a point distant from the distal electrodes, ideally the AIMD housing, this minimizes or eliminates hazards associated with overheating of said distal electrodes during diagnostic procedures, such as MRI. Another purpose of these low ESR diverter capacitors and related lowpass filter circuits is to provide electromagnetic interference (EMI) filtering in order to protect sensitive AIMD electronic circuits from malfunctioning in the presence of MRI RF noise.

For maximum RF energy transfer out of the lead, frequency selective diverter circuits are needed to decouple, and transfer energy induced onto implanted leads from the MRI RF-pulse field to an energy dissipating surface. Importantly, while decoupling and transferring such energy, it is extremely important that the diverter circuits do not themselves overheat thereby creating hot spots on the AIMD housing, which can damage biological tissue, such as, in a pacemaker pectoral pocket. Recent experiments by the inventors resulted in temperature rises from 4° C. to 10° C. on a pacemaker housing directly over the location of the feedthrough capacitor during a 4 watt/kilogram MRI scan. In general, prior art MLCC chip capacitors are really not indicated for high power RF applications. The reason for this is that the impedance (capacitive reactance) drops so low that extremely high RF currents end up flowing through the MLCC chip capacitor's electrode plates. During a 4 watt/kilogram MRI scan where 16 to 20 volts may be induced at the AIMD input, the diverter MLCC chip capacitor may be handling anywhere from 0.5 amp to 4 amps of RF current. If the ESR of the MLCC chip capacitor, for example, is 0.5 ohm and the MLCC chip capacitor is diverting 2 amps, then the I^2R loss is on the order of 2 watts. Two watts of dissipation on this small MLCC chip capacitor component causes the MLCC chip capacitor to overheat significantly. The present invention resolves these issues and provides other related advantages.

In summary, the RF diverting circuits, in general, conduct MRI induced RF energy from the lead or its associated leadwires to an EDS such as the housing 124 of the AIMD. The design of the diverter circuit is very important. First of all, the diverter circuit should appear as a very low impedance at MRI RF frequencies such that a maximum amount

of RF energy is diverted from the implantable lead to the EDS. In addition, it is also desirable that the diverter capacitor element be designed such that it does not overheat.

The mounting location of the diverter capacitor within an AIMD is also typically constrained by proper EMI design practices. Generally, EMI filters are designed such that undesirable RF energy is diverted at the point of leadwire ingress to the AIMD housing, instead of letting the EMI inside the AIMD housing and then trying to filter said EMI further downstream in the AIMD circuit path, for example, filtering at an internal circuit board instead of at leadwire ingress. In an embodiment, at least one of the low ESR diverter MLCC chip capacitors of the present application is mounted directly to the multi-pin hermetic feedthrough of the AIMD. This is an ideal location both to divert RF energy before it can enter the AIMD housing and this is also optimal for heat conduction and dissipation. Even with low ESR, the diverter MLCC chip capacitor will still be dissipating a significant amount of energy. This means, even with low ESR, the diverter MLCC chip capacitor is creating heat which must be conducted or convected away so that a hot spot does not occur on the AIMD housing at or near the filter capacitor. Therefore, by diverting both the RF energy and heat to the relatively large surface area of the housing of the AIMD, the MRI RF energy can be dissipated with only a small temperature rise, which does not adversely affect body tissue.

It is noted that the general principle of placing a primary filter capacitor (energy diverter) at the point of leadwire ingress in the AIMD housing is generally the preferred EMI design practice. For relatively low frequencies, such as an MRI RF-pulse frequency of 64 MHz, it is perfectly acceptable, however, to place the primary diverter filter capacitor on a circuit board remote from the hermetic feedthrough otherwise known as the point of leadwire ingress.

FIG. 49 illustrates a family of lowpass filters, which is very similar to the family of lowpass filters described in FIG. 37. The lowpass filters of FIG. 49 are also known as EMI filters, meaning that they allow low frequencies to pass, but provide a substantial amount of attenuation at higher frequencies. As previously disclosed, the lowpass filters 260 of FIG. 37 incorporate a variety of capacitor designs ranging from a simple MLCC chip capacitor "C" to a three-terminal "feedthrough filter capacitor-FTC". These diverter capacitors can be combined in various ways with inductors to form "L", "reverse L", "T", "Pi" (t), "LL", "reverse LL" or "n" element lowpass filters. As can be seen in FIG. 49, there is a capacitor element 210' in every one of the circuits that is directed towards the implantable lead electrode (body fluid side). The conduction path is from the electrode of the implantable lead, which is in contact with biological tissue, along the conductor of said implantable lead through the hermetic feedthrough of the AIMD along the feedthrough terminal pin directly to the capacitor 210'. In accordance with the present invention, the capacitor 210' is a high RF power, low ESR handling capacitor so that the capacitor 210' and the AIMD will not overheat in an MRI environment. One will also note that the n-element filter has been revised so that there is no longer an inductor directed toward the implantable lead electrode. The version of the LL filter, with the inductor directed to the implantable lead electrode has also been eliminated. In addition, the version of the two-element or L filter, with the inductor toward the implantable lead electrode has also been eliminated. These elements are eliminated because, in the present invention, it is very important that the primary high-power RF handling capacitor have a direct connection from its active electrode plates

through the hermetic feedthrough to the one or more electrodes of the implantable lead.

Referring once again to FIG. **49**, for the n-element, LL and Pi (π) filters, one can see that there are two capacitors **210'** and **140** separated by an inductor. In the present invention, it is critical that capacitor **210'** have an ESR<0.5 ohm at the MRI RF-pulse frequency and be made with a dielectric material having a dielectric constant k<1,000. This is so that it the capacitor **210'** can have a high electrode plate count and a very low equivalent series resistance at MRI pulse frequencies. The capacitor element **140** can be constructed of a low ESR construction the same as capacitor **210'** or capacitor element **140** can alternatively be constructed as prior art filter capacitors are typically constructed and that is with conventional ceramic dielectrics having a k>1,000. Another way of looking at this is that the first capacitor directed toward the implanted electrode is the work horse and is going to do the bulk of the diverting of RF energy from the lead, diverting it to the AIMD housing where the energy and or heat can be dissipated over a large surface area.

As a point of reference, the first EMI filter ever designed for an active implantable medical device was in the mid-1970s for the Xytron Medtronic pacemaker. These were unipolar feedthrough capacitor EMI filters that had a k>1, 200. The principle designer on this filter design project was Robert Stevenson, one of the co-inventors herein. The next EMI filter to be designed for cardiac pacemaker was in 1979 for a St. Jude pacemaker. Robert Stevenson worked with St. Jude Vice President Buehl Truex to design in this filter, which generally had a k>2,200. The inventors herein have spent their entire careers designing EMI filters for a variety of applications, including AIMD applications. This is significant in that there has never been a case where the primary passive EMI lowpass filter (the work horse filter) had a k<1,200. In addition, the inventors have either been asked to bid, have been aware of, or have cross-sectioned and analyzed explants of other manufacturer's EMI filters and have found the same thing to be true and that is, prior art EMI filters have consistently been built around a dielectric structure that has a k of at least 1,200. For the last 30 years, almost all primary EMI filters (the work horse filter) have been designed with a k of greater than 1,200. There are several reasons why the industry has always designed EMI filters having a k of about 1,200 (and generally above 2,00 to 2,200). The first important reason is that active implantable medical devices must be very small in size and very low in weight. Another consideration is cost. By using a high k dielectric, one needs fewer electrode plates and can build the capacitor much thinner and in a much smaller overall volume or footprint. This is ideal for all AIMDs, again, where size and weight are critical. Until the MRI application came along, on which this patent focuses, it was never contemplated to do what is completely counterintuitive and that is to use a low k capacitor for AIMD filtering.

The parent application claims primary passive diverter capacitors (work horse capacitors) having k<200. There is also a general reason for this and that is that the major material suppliers in the ceramic dielectric industries, such as Ferro, typically offer dielectrics either above 1,200 k or below 200 k. As previously disclosed, the dielectrics below 200 k are known as Class 1 dielectrics. These Class 1 dielectrics find broad application in military and space applications, however, have never been used for the primary EMI lowpass filter capacitor for an AIMD until now. There is a vast desert in terms of material supply in the dielectrics industry in that there are almost no suppliers of dielectric

materials having k between 200 k and 1,000 k. There are a couple of specialty ceramic powder manufacturers, one of which is Dimat, Inc. Dimat offers a range of specialty dielectrics, including an N2200, which has a dielectric constant of 250; an N3300, which has a dielectric constant of 400; an N4700, which has a dielectric constant of 600; and, an N5250, which has a dielectric constant of 700. There is also another company called MRA Materials, which offers a dielectric with a k of 485 and also a dielectric with a k of 600. Nevertheless, none of the specialty or niche dielectrics companies have ever used or suggested use of such low k dielectric materials for a primary lowpass EMI filter for an AIMD. The present application teaches and claims that the primary EMI filter capacitor, which is directly connected through wiring to an implantable lead conductor with distal electrodes, comprises a k<1,000. There is a practical reason for this. In some cases, the capacitance value can be considerably high, such as 1,800-pF. Building this capacitor out of a common commercially available dielectric, such as NP0 (having a k of 90) results in a capacitor that has so many electrode plates that it is often too thick to fit into a cardiac pacemaker. Accordingly, the inventors developed a mid k (intermediate) dielectric (between 200 k and 1,000 k), which presents an ideal tradeoff between volumetric efficiency, a lower k, a higher number of electrode plates and, correspondingly, an ESR of less than 0.5 ohm that will meet all of the design criteria, including small in size, low in weight and low in cost while effectively filtering.

In the embodiments herein, it is possible to split the primary capacitance, the primary capacitance comprising a primary diverter lowpass filter capacitor, which is the work horse capacitor of the AIMD, by breaking up said primary capacitance into two areas. Referring to FIG. **37**, shown is a primary capacitance broken up using two different capacitors, for example but not limited to, a feedthrough filter capacitor (FTC) **210'** and a board mounted capacitor MLCC chip capacitor **210**. In a preferred functional primary capacitance design, the exemplary first capacitor **210'** has a dielectric constant of less than 1,000 and even preferably less than 200. For example, for a needed overall functional primary capacitance value of 1,800-pF, the high-energy, low ESR first capacitor **210'** can be 800-pF and the second board mounted capacitor **210** can be 1,000-pF. It is noted that the exemplary second board mounted capacitor **210** can be conventional technology with a dielectric constant above 1,000. Hence, the first capacitor **210'** and the second board capacitor **210** add up in parallel to provide 1,800-pF, which is the functional primary capacitance design goal. The advantage of functionally designing primary capacitance in this way is that the first capacitor (FTC) **210'** is thinner, thereby facilitating packaging of both the first capacitor and the AIMD circuit board. The capacitance values of 800-pF and 1,000-pF are chosen at random and are not necessarily representative of any particular functional primary capacitance design. In other words, the first capacitor **210'** can have a capacitance of 200-pF and the board capacitor **210** can have a capacitance of 1,600-pF. Accordingly, a functional primary capacitance design comprises a first capacitor and one or more additional capacitors, the first capacitor comprising a first capacitance value and a dielectric material having k<1,000, and the one or more additional capacitors each comprising an additional capacitance value such that the sum of the first capacitance value and the additional capacitance values achieve a desired overall functional primary capacitance value. Furthermore, the capacitance value of the first capacitor and the capacitance value of the one or more additional capacitors may comprise any capaci-

tance value in any value combination to achieve the desired overall functional primary capacitance value.

In summary, a primary filter capacitor (that is, a work horse filter capacitor) having a dielectric constant of less than 1,000 has never been built for use in AIMDs having a direct connection to the conductor of an implantable lead, the implantable lead having an electrode in contact with body tissues. As this application teaches, one of the reasons for this is that designing a capacitor with a dielectric constant of less than 1,000 is completely counterintuitive for incorporation into AIMDs, as such capacitors require high number of electrode plates typically making such low k capacitors too big for AIMDs. Moreover, it is only with the advent of MRI conditional AIMD systems and implantable leads and the recent discovery that a primary filter capacitor itself can substantially overheat during MRI scanning, causing the housing 124 of an AIMD implanted in a pectoral pocket to excessively overheat such that the patient can actually feel a burning discomfort in the pectoral area of the chest, that primary filter capacitors with a k<1,000 have become an attractive filtering design solution. While dielectric constant capacitors (k<1,000) require a high number of electrode plates for the ESR of the capacitor to be sufficiently low such that when the capacitor diverts RF energy (up to 6 amps) at MRI RF frequencies, the capacitor itself will not overheat, the present application teaches embodiments having sufficient number of electrode plates to reduce the electrode resistance of the capacitor in combination with a dielectric material having a dielectric constant k<1,000 such that the primary filter capacitor (the working horse capacitor) alone or in combination with one or more additional capacitors enables low ESR. As the ESR of a capacitor at high frequency is primarily an ohmic loss, and assuming all other electrical connections are solid, the ESR essentially comprises only the resistance of the electrode plates. Increasing the number of electrode plates significantly reduces ESR of low k capacitors. Dielectric constant selection of the dielectric material of the capacitor in combination with the number of electrode plates provides for overall functional primary capacitance value.

In the embodiments herein, the goal is to drop ESR substantially so that insignificant heat is produced by the filter capacitor itself and undue undesirable AIMD implant pocket heating does not occur. The FDA and the industry generally limit implant pocket heating to about 4° C. It has been demonstrated through experiments by the inventors that the combination of overheating of prior art primary lowpass filter capacitors with a k greater than 1,200 can by themselves result in the AIMD housing and the corresponding human pocket overheating significantly above 4° C. The embodiments disclosed herein resolves such heating problems among other related advantages.

Referring once again to FIG. 37, noted is a variation between the circuit diagrams of the "LL" and "reverse LL" as compared to the "L" and "reverse L". Referring to the LL filter, one can see that there is a capacitor 210 to the left of the inductor on the left-hand side circuit diagram. For the reverse LL, there is an inductor to the left of a capacitor 210 on the right-hand side circuit diagram. Referring to the L filter, one can see that the inductor is to the left of the capacitor 210 on the left-hand side circuit diagram (instead of the capacitor 210 being to the left of the inductor as shown by the LL circuit diagram). Similarly, for the reverse L filter, the capacitor 210 is to the left of the inductor on the right-hand side circuit diagram (instead of the inductor being to the left of the capacitor 210 as shown by the reverse LL circuit diagram). FIG. 37 illustrates that there is really no

industry standard on what constitutes a reverse L or a reverse LL filter. In fact, when manufactured, as such filters can be installed by the user in either direction. As such, FIG. 49 illustrates a reverse L filter and a reverse LL filter both ways to emphasize that there really is no industry standard between the terms LL and reverse LL or L and reverse L. Hence, the reference in the claims to the LL, the reverse LL, the L and the reverse L filters refer to the specific electrical schematic shown in FIGS. 37 and 49 as well as in other detailed schematic diagrams herein.

Referring once again to FIG. 49, one will see that for a single element capacitor, said single element capacitor can be a two-terminal device "C" such as an MLCC chip capacitor or a three-terminal device "FTC" such as a feedthrough filter capacitor. It is understood by those skilled in the art that any of the capacitors 210' shown in FIG. 49, can be two-terminal capacitors "C" or three-terminal capacitors "FTC", wherein the two-terminal capacitors may comprise one of an MLCC chip capacitor, an X2Y attenuator, or combinations thereof; and wherein the three-terminal capacitor may comprise one of a feedthrough filter capacitor, an X2Y attenuator, a flat-through capacitor or combinations thereof. It is noted that X2Y attenuators comprise both two-terminal and three-terminal design configurations.

Referring once again to FIG. 49, one can see that the attenuation versus frequency insertion loss curve for the three-terminal single element feedthrough filter capacitor "FTC" does not have a significant resonant dip at high frequencies. However, when one refers to the insertion loss curve for a single element two-terminal MLCC chip capacitor "C", one can see that the single element two-terminal MLCC chip capacitor has a significant resonant dip at high frequencies shown as self-resonant frequencies f_r. Such self-resonant frequencies f_r of the MLCC chip capacitor is due to significant equivalent series inductance 204 as shown in the MLCC chip capacitor equivalent circuit diagram of FIG. 25. When a capacitor has equivalent series inductance, there is always going to be some frequency at which the capacitive reactance is equal and opposite to the inductive reactance. This is known as the self-resonant frequency of the capacitor. Observable in FIG. 49 is an insertion loss peak at the capacitor's self-resonant frequency f_r. The two-terminal single element MLCC chip capacitor insertion loss versus frequency curve goes to infinity if it were not for the MLCC chip capacitor's equivalent series resistance. In other words, the MLCC chip capacitor has infinite attenuation in dB if not for the capacitor's equivalent series resistance (ESR). The problem of a decreasing insertion loss of the MLCC chip capacitor occurs at frequencies above its self-resonant frequency f_r. At higher frequencies above a self-resonant frequency, the inductive reactance becomes increasingly dominant, which undesirably reduces the filter attenuation in dB. Well mounted feedthrough filter capacitors tend to have essentially zero equivalent series inductance 204 as shown in FIG. 25 and therefore have a more ideal filter attenuation versus frequency insertion loss curve.

FIG. 49A reads on FIG. 39 and FIG. 39A. In FIG. 39, disclosed is that one can split up the functional primary filter capacitance of an AIMD into, for example, a feedthrough filter capacitor FTC 210' and a board-mounted capacitor MLCC chip capacitor 210a. Referring to FIG. 49A, the schematic diagram illustrates an exemplary embodiment of an FTC 210' in accordance with the present invention having a k<1,000 and extremely low ESR properties (an ESR of <2 ohms at the MRI RF-pulse frequency) in parallel with a board-mounted capacitor MLCC chip capacitor 210 (or 140'). The MLCC chip capacitor 210 (or 140'), can also have

a k<1,000 (embodiment 210) in accordance with the present invention, or can have a k<200 (embodiment 210), or can be a prior art MLCC chip capacitor having a k>1,000 (embodiment 140'). Also shown in FIG. **49**A is the composite insertion loss curve of the FTC **210'** in parallel with the MLCC chip capacitor **210** (or **140'**). The dashed line (labelled MLCC ONLY) represents the effect on attenuation as a function of frequency if the filter comprised only an MLCC chip capacitor. One can see that the attenuation of a filter having only an MLCC chip capacitor reaches a maximum and then degrades at higher frequencies. With the low k feedthrough filter capacitor FTC **210'**, which as previously disclosed has zero series inductance at high frequencies, one can see that the attenuation picks up (lifts up) the degradation and insertion loss that occurs from the MLCC chip capacitor only (in other words, improves attenuation at the high frequencies); hence, splitting up the functional primary filter capacitance of the filter between the FTC **210'** and the MLCC chip capacitor **210** (or **140'**) yields an overall combined broadband lowpass filter attenuation performance which is preferred for AIMD EMI and MRI filters, as such filters provide electromagnetic interference (EMI) protection to sensitive active AIMD electronics and also handle RF energy or heat induced in an AIMD lead from an external RF field at a selected MRI frequency or a range of MRI frequencies.

Referring back again to FIG. **49**, one can see that each one of the lowpass filter circuits has a phantom inductor L' drawn with dashed lines. The phantom inductor L' is included in order to acknowledge that all conductors have some amount of series inductance and that the amount of inductance is in series between the primary work horse capacitor (in the example FTC **210'**) and the distal lead conductor electrode. The embodiments of the present application targets such series inductances so that said series inductance L' is kept as low as possible (as close to zero as practical). If series inductance is too large, then a large inductive reactance occurs at MRI RF-pulse frequencies, thereby reducing the amount of energy that can be pulled from the lead. In other words, it is desirable that the first thing connected to the implantable lead electrode along the path of the implantable lead is the work horse capacitor (such as the exemplary FTC **210'**) so that said work horse capacitor can draw maximal energy out of the implanted lead. It is also critical that the work horse capacitor be very low in ESR, so that said work horse capacitor does not overheat while drawing literally amps of MRI induced energy out of the implanted lead. Many implantable leads themselves are made of spiraled or of coiled construction and some of these are insulated, while others are not insulated. The uninsulated lead conductors tend to short together, particularly when going through tortuous paths, such as bends in a venous system. Therefore, the parasitic conductance of the uninsulated leads will vary significantly due to design and lead trajectory differences. As such, the phantom inductors L' of FIG. **49** are meant to acknowledge that, pending AIMD system and lead design, some parasitic inductance can be associated with the direct connection of the primary work horse capacitor (for example, FTC **210'**) and a distal electrode. In summary, it is particularly important that the parasitic inductance be minimized from the point of leadwire ingress into the AIMD housing, that is, from the point where the leadwire passes through the conductive pathway of the insulator of the hermetic feedthrough. It is also very important that there be insignificant or very little parasitic inductance between the

work horse capacitor and that point of leadwire ingress into the device side of the AIMD, namely inside of the AIMD housing.

FIG. **50** illustrates that a high energy dissipating low ESR capacitor **210'** can be used in combination with other circuits, such as bandstop filter **258** and/or an L-C trap filter **262**, the bandstop and the L-C trap filters each consisting of a capacitor **140** or **210** and an inductor L. Again, the capacitor of the bandstop filter **258** and the capacitor of the L-C trap can be conventional prior art filter capacitors or can be low k capacitors. Regardless, capacitor **2101** is the work horse capacitor and must comprise very low in ESR in accordance with the present invention, in other words, must be a low k capacitor.

FIG. **51** and FIG. **52** illustrate an MLCC chip capacitor **210** that is similar in its exterior appearance to the prior art MLCC chip capacitor **140'** previously described in FIGS. **14** and **15**. In accordance with the present invention, the MLCC chip capacitor **210** of FIGS. **51** and **52** comprises a dielectric material having a k<1,000 and an ESR of <0.5 ohm at the MRI RF-pulse frequency(ies). Also, in accordance with the present invention, The MLCC chip capacitor **210** comprises a relatively high number of active electrode plates **144** and ground electrode plates **146** compared to the prior art MLCC chip capacitor **140'** of FIGS. **14** and **15**.

FIG. **53** is the electrical schematic of FIGS. **51** and **52** showing that the ESR of MLCC chip capacitor **210** is less than 0.5 ohm.

FIG. **54** is a bipolar hermetic feedthrough having a metallic ferrule **134** and two terminal pins **142a** and **142b** passing through the insulator **156** in insulative relationship with the conductive ferrule **134**. There are two MLCC chip capacitors **210a** and **210b**, as illustrated in FIGS. **51** and **52**, connected respectively to terminal pins **142a** and **142b**. The MLCC chip capacitors are shown attached to a gold braze **154a**, the gold braze hermetically sealing the insulator **156** to the ferrule **134** of the hermetic feedthrough so that an essentially oxide-free (oxide-resistant) and low resistance electrical connection is made. Such oxide-resistant electrical connections are more thoroughly disclosed in U.S. Pat. No. 6,765,779, the content of which is fully incorporated herein by this reference. MLCC chip capacitors attached to a gold braze of a hermetic feedthrough are also disclosed in U.S. Pat. No. 10,080,889, the content of which is fully incorporated herein by this reference.

Referring now back to FIG. **19** of the present application, it is contemplated that the MLCC chip capacitor **210** of FIGS. **51** and **52** can also be mounted to a substrate **147** as shown in FIG. **19**. Additionally, the MLCC chip capacitor **210** can be mounted on a circuit board. Moreover, the substrate and/or the circuit board can be mounted to the hermetic feedthrough adjacent one of the ferrule **134**, the insulator **156**, or both the ferrule and the insulator in accordance with the definition of adjacent previously disclosed. Furthermore, such circuit boards and substrates can be mounted immediately adjacent the hermetic feedthrough, distant from the hermetic feedthrough or even at a remote location of the hermetic feedthrough. As defined herein, the remote location is still inside of the AIMD housing, but located remotely from the hermetic terminal, including the feedthrough ferrule and/or insulator.

FIG. **55** is a schematic diagram of the bipolar filtered hermetic feedthrough of FIG. **54**.

FIG. **56** is similar to FIGS. **6** and **39** illustrating a breakaway cross-section of a typical AIMD, such as a cardiac pacemaker, except that instead of a feedthrough capacitor (**140** of FIG. **6** and **210'** of FIG. **39**) attached

adjacent the ferrule **134** of the hermetic feedthrough, a circuit board having filter MLCC chip capacitors are attached to the hermetic feedthrough. As previously disclosed, prior art feedthrough capacitors such as the feedthrough filter capacitor **140** of FIG. **6**, and which are used for primary EMI filtering of AIMDs, have always been built from dielectric materials having k>1,000 k. The feedthrough filter capacitor **210'** of FIG. **39** has a dielectric material having k<1,000.

Referring to FIG. **56**, illustrated is a circuit board **130** similar to the circuit board **130** previously illustrated in FIG. **39**, however, in this case, each of the device side terminal pins **142** of the quad polar hermetic feedthrough **132** are attached to a respective MLCC chip capacitor **210a** through **210d**. The MLCC chip capacitors **201a** through **210d** are low ESR (low k MLCC chip capacitors having k<1,000) in accordance with the teachings of FIGS. **51** and **52**. The leadwires **136a** through **136d** of the hermetic feedthrough **132** each connect on the device side terminal pin **142** to an active capacitor metallization **164** (not labelled) of their respective low k MLCC chip capacitor **210a** through **210d**. These extremely low ESR (low k) MLCC chip capacitors functionally draw a great deal of RF energy and/or heat from an implanted lead when in an MRI environment. It is important that this RF energy be efficiently dissipated to the AIMD housing **124**, wherein the RF energy can be dissipated as RF energy and/or heat. As such, there is a low inductance ground circuit trace **182**, which provides a ground connection to the ground capacitor metallization **166** (not labelled) of each MLCC chip capacitor **210a** through **210d** to each respective device side terminal pin **142** of leadwires **136a** through **136d**. This efficiently diverts RF energy from the leadwires **136a** through **136d** to the ground circuit trace **182**. There is also an optional RF grounding strap **264** attached to ground circuit trace **182**. The RF grounding strap **264** may be used to substantially reduce inductance making the filter circuit board **130** more efficient for diverting the RF energy to the AIMD housing **124** at high frequencies. The circuit trace may comprise may have increased width commensurate with the connection pad to which the RF grounding strap **264** is attached. The RF grounding strap may be substantially wide compared to its thickness. In an embodiment, the RF grounding strap may comprise a width >4 times its thickness.

FIG. **56A** is a schematic diagram of the primary work horse filter MLCC chip capacitors **210a** through **210d** illustrated in FIG. **56**. Shown are each one of the work horse low ESR filter MLCC chip capacitors **210a** through **210d** in series with a parasitic inductance LP. This parasitic inductance L_P comprises the inductance of the leadwire, from the length of the leadwire at the point of leadwire ingress, through the hermetic feedthrough, to the circuit board connection, to the MLCC chip capacitor (the four MLCC chip capacitors **210a** through **210d** are represented in the schematic diagram of FIG. **56A**). The parasitic inductance L_P also includes the inductance of the ground circuit trace **182** and the RF grounding strap **264**. It is desirable to keep this parasitic inductance LP as low as possible. That is why the ground circuit traces **182** and the RF grounding strap **264** are relatively wide. It is also important to minimize the inductance of the device send terminal pin **142** between the hermetic feedthrough and the active end (non-ground end) of the primary filter MLCC chip capacitors **210a** through **210d**. This can be done by making the device end terminal pin **142** shorter, larger in diameter, flat, rectangular or a combination thereof.

Referring once again to FIG. **56**, one can see that the leadwires **136** of hermetic feedthrough **132** are directed to via holes in the multi-layer circuit board **130**. The via hole of the multi-layer circuit board **130** comprises a via hole metallization to which the active capacitor metallization **164** (on the left-hand side of the MLCC chip capacitors not labelled) of the filter MLCC chip capacitors **210a** through **210d** is attached. The active metallization **164** provides electrical connection to the active electrode plates of the MLCC chip capacitor. The device side terminal pins **142** pass through the via holes in the multi-layer circuit board **130** to the layers of said multi-layer circuit board, wherein the device side terminal pins **142** contact active circuit traces shown as dashed lines (hidden lines). Thus, the circuit from the body fluid side leadwires **136** through the primary filter MLCC chip capacitors **210a** through **210d** through the circuit traces of the multi-layer circuit board **130** to the ground circuit trace **182**, wherein the ground circuit trace **182** connects to other via holes (not shown), is completed. The not via holes (not shown) connected to the ground circuit **182** are connected to other AIMD electronics, such as an ASIC electronics chip or other AIMD circuits.

FIG. **57** is very similar to FIG. **56** except that an overvoltage diode protection array **181** has been added. It is very common in the input circuitry of AIMDs to provide an overvoltage protection diode array **181** mainly against the use of automatic external defibrillators (AEDs). AEDs can induce a very large high voltage pulse into implanted leads and the high voltage of such a pulse can be undesirably directed toward sensitive AIMD electronic circuits. Thus, the overvoltage protection diode array **181** provides high voltage overprotection for each one of the quad polar leads **136a** through **136d** to ground, which in FIG. **57** is the AIMD housing **124**.

Overvoltage protection is better understood by referring to the schematic diagram of FIG. **58**, which is representative of the AIMD system of FIG. **57**. One can see that there is a continuous electrical circuit connection from the implantable lead electrode to the AIMD circuits. Leadwires **136a** through **136d**, the low ESR high RF-energy dissipating capacitors MLCC chip capacitors **210a** through **210d** of the present invention and a high voltage protection diode array **181** are continuously connected. Each MLCC chip capacitor **210a** through **210d** remains the work horse capacitor as the primary diverter of high frequency MRI RF energy/heat to the AIMD housing **124**. It is noted that the embodiment of FIG. **57** illustrates the circuit ground path to the AIMD housing **124** comprising an RF grounding strap **264**. The overvoltage diode protection array **181** of FIG. **58**, now part of the circuit between the implantable lead electrode and the AIMD circuits, is positioned on the left-hand side of the MLCC chip capacitors **210a** through **210d**.

FIG. **59** is very similar to FIG. **58** except that the high voltage protection diode array **181** is shown on the right-hand side of the low ESR capacitors MLCC chip capacitors **210a** through **210d** of the present invention. Since the high voltage protection diode array **181** is not in series, but is in parallel with the low ESR capacitors, it is understood by one of ordinary skill in the art that the low ESR MLCC chip capacitors **219a** through **210d** can be placed anywhere along the length of the leadwires **136a** through **136d**. Regardless of where the high voltage protection diode array **181** is positioned, it is understood that the low ESR capacitor of the present invention is always directly connected by way of continuous electrical circuit connections, such as the circuit connections to the circuit pads of the circuit traces illustrated in FIG. **57**. Thus, a continuous electrical path between the

AIMD circuits and the implantable lead electrode contactable to biological cells through the leadwires of the hermetic feedthrough therebetween is provided.

Referring once again to FIG. **58**, one will notice that the diodes of the overvoltage protection diode array **181** are back-to-back so that said diodes can clamp and shunt a positive or a negative polarity pulse. For AEDs, it is common for shocking pulses to be biphasic, meaning that the shocking pulse switches polarity. Therefore, it is common practice to orient the diodes of the overvoltage protection diode array **181** back-to-back so that the diodes may shunt energy having both positive and negative polarities. It is noted that the diodes of the overvoltage protection diode array **181** must be positioned before or after the primary EMI low ESR capacitor before placing any other electronic components like electronic chips, ASIC chips, active filters or other sensitive electronics in this portion of the circuit path, as such electronic components are the very components that can be damaged by an overvoltage or can be interfered with by EMI. As a result, in general, such 'sensitive' AIMD electronic components are always positioned downstream (to the right) of the circuits of FIG. **58** or **59**.

FIG. **60** is an alternative diode connection for the circuit schematics of FIGS. **58** and **59**. FIG. **60** illustrates that instead of two discrete separate diodes wired back-to-back, the diodes of an overvoltage protection diode array **181** can be alternatively placed back-to-back in series. Sometimes such back-to-back series diode arrays are called Transorbs©. Ii is understood that, in general, the diodes of the overvoltage protection diode array **181** can be selected from the group consisting of a transient voltage suppressor, a varister, an avalanche diode or a Zener diode.

FIG. **61** is very similar to FIG. **56** except that the RF grounding strap **264** has been replaced with a simple RF grounding leadwire **264'**. An RF grounding leadwire **264'** works okay at relatively low RF frequencies. For example, for a 1.5 Tesla scanner, the RF-pulse frequency is 64 MHz. As scanners have evolved to higher and higher frequencies, the inductance of such a small wire can become problematic. For example, there are many modern scanners in the market operating at 3 Tesla, which means that the RF frequency is 128 MHz. The inductive reactance is equal to $2 \times \pi \times$ frequency×inductance. So, if the inductance is small and the frequency is large, one can get a great deal of inductive reactance which makes the diversion of high frequency energy through the primary low ESR chip capacitors **210** less efficient. Another way of saying this is that you really don't want anything in the ground path that impedes diverting the high frequency RF energy to the AIMD housing **124**. One way around this (not shown) is to use multiple RF grounding leadwires **264'**, thereby creating additional circuit paths to ground and reducing the inductance.

FIG. **62** is very similar to FIG. **61** except in this case, a grounding leadwire **264"** is routed directly from the ferrule **134** of the hermetic feedthrough **132** to the ground circuit trace **182** of the AIMD circuit board **130** (not labelled).

FIG. **63** and FIG. **64** are very similar to the prior art flat-through type feedthrough capacitor of FIGS. **17** and **18**. These flat-through type capacitors are unique in that the circuit current must pass through the flat-through capacitor's own active electrode plates instead of through a feedthrough leadwire **136** extending through a metallized via electrically connecting the active electrode plates **144** as shown in the feedthrough filter capacitors **140** of FIGS. **7-10**. Regarding FIGS. **63** and **64**, the circuit current i_1 of the flat-through capacitor **210"** is shown entering the active electrode plates **144** as i_{1a} and exiting said active electrode plates as i_{1b}.

FIG. **64**A is the circuit diagram of the flat-through capacitor **210"** of FIGS. **63** and **64**. Illustrated is that the flat-through capacitor **210"** is a three-terminal filter capacitor. However, instead of having a leadwire **136** going through the center of the three-terminal capacitor as illustrated in the schematic diagram of the feedthrough filter capacitor **140** of FIG. **11**, one actually has the active electrode plates **144** going through the center of the three-terminal flat-through capacitor **210"**. The circuit current (not shown) of FIG. **11** passes to the active electrodes plates **144** of a three-terminal feedthrough filter capacitor by way of the leadwire **136**, while the circuit current **180** of the flat-through capacitor **210"** of FIG. **64**A passes through the active electrode plate **144** itself. In accordance with the present invention, the capacitor dielectric of the flat-through capacitor **210"** has a k greater than 0 but less than 1,000, k<1,000, and an ESR generally less than 0.5 ohm at an MRI RF-pulse frequency including an MRI RF-pulse frequency of 64 MHz (1.5 T) and 128 MHz (3 T).

Referring once again to FIG. **63**, one can see that the flat-through capacitor **210"** is installed on an AIMD circuit board **130** (not shown) a little differently. Installation of the flat-through capacitor **210"** of FIG. **63** require circuit traces **178a** and **178b**. Circuit traces **178a** and **178b** are made on a circuit board substrate such that the end metallizations of the flat-through capacitor **210"** can properly be attached, in other words, the circuit traces **178a** and **178b** of the circuit board are positioned to accommodate a flat-through capacitor attachment. Such circuit traces are separated by an insulating area, that is, there is a break in the circuit trace, such that, when the flat-through capacitor **210"** is attached to the circuit traces **178a** and **178b**, a circuit current i_1 can pass all the way through the active electrode plates **144** from the left-hand side of the flat-through capacitor, labelled ha, through the active electrode plates **144**, to the right side of the flat-through capacitor, labelled ill). As shown, i_1 is going from the left-hand side to the right-hand side, but it is understood that i_1 can also pass through the active electrode plates in the opposite direction, namely from the right-hand side to the left-hand side of the flat-through capacitor **210"** depending on the AIMD therapeutic algorithms.

Referring once again to FIG. **63**, one can see that there is a ground connection **182a** and **182b**. This ground connection is routed to the AIMD housing **124**.

Referring once again to FIG. **64**A, the schematic diagram of the flat-through filter of FIGS. **63** and **64** shows that the circuit current i_1 passes through the flat-through capacitor at an input terminal **178a** (terminal 1) and then exits the active capacitor electrode plates **144** at an output terminal **178b** (terminal 2). It is appreciated that the flat-through capacitor being a three-terminal device is symmetrical, meaning that the attachment of the flat-through capacitor **210"** to the circuit can be reversed and still operates in the same fashion. Referring again to FIG. **63**, it is noted that the left-hand side of the flat-through capacitor **210"** has been arbitrarily labelled as the body fluid side and the right-hand side as the device side. As previously disclosed, electromagnetic interference (EMI) can be coupled or radiated to body fluid device side leads and electrodes and can undesirably appear as an RF current ha at the input terminal **178a** (terminal 1) of the flat-through capacitor **210"**; it is noted that i_1 also comprises low frequency therapeutic pacing pulses or biologic signals in addition to any EMI RF current. Such EMI passes through the active electrode plates **144** of the flat-through capacitor **210"** and is continuously decoupled through capacitive filter action to the ground electrode plates **146** (terminal 3). When the current i_{1b} exits at the device side

terminal **178***b* (terminal **2**), the EMI has been greatly attenuated (filtered) such that said EMI can no longer dangerously interfere with AIMD circuitry. As shown, the attenuated current i_g is diverted (filtered) to ground, which as shown is the ferrule **134** of the hermetic feedthrough **132** (not shown). This three-terminal filter behavior is very similar to feedthrough filter capacitors, which are also three-terminal devices. The difference is that, for a feedthrough capacitor, circuit currents pass through a leadwire, such as leadwire **142** illustrated in the prior art feedthrough filter capacitors of FIGS. **7** to **10**, while the circuit currents for flat-through capacitors flow through its own active electrode plates **144**. Therefore, it is important that the active electrode plates **144** be robust and low in DC resistance, Typically, this means that a relatively large number of active electrode plates **144** appears in parallel and interleaves between ground electrode plates **146**. By having additional electrodes in parallel, one reduces the overall resistance to the flow of current, otherwise known as DC resistivity.

In accordance with the present invention, the embodiments, which comprise a first filter capacitor, meaning the first capacitor from the point of implanted leadwire ingress that EMI encounters, has a k greater than zero and less than one thousand, k<1,000. This is distinct and in marked contrast to prior art filter devices, which generally have dielectric constants of k greater than 1,200, or 2,500, or even higher. By reducing the dielectric constant of the filter capacitor, an increase in the number of active electrode plates **144** and ground plates **146** is required in order to achieve an equivalent capacitance value and amount of filtering comparable to that of prior art high k, k>1,200 filter capacitors. This makes the low k flat-through capacitors **210"**, as illustrated in FIGS. **63** and **64**, highly suitable for use in AIMDs, as the higher number of active electrode plates **144** of such low k, k<1,000, flat-through capacitors **210"** reduce the DC resistance of said low k flat-through filter capacitors. It is noted that it is also important that the impedance of the active electrode plates **144** of the low k flat-through capacitors also be low. However, if the low k flat-through capacitors have inductance L as shown in FIG. **64**A, the inductance L shown aides in the EMI filtering because this inductance L is along the i_1 circuit path. It is noted that at high frequencies, such as EMI RF frequencies, the inductive reactance is given by the equation XL=2πFL. This means that at high frequencies, the amount of inductance reactance becomes very high thereby further impeding EMI from undesirably entering from the body fluid side to the device side of an AIMD.

Referring once again to FIG. **64**A, shown is that EMI can radiate across a flat-through capacitor. The potential for radiating EMI across a flat-through capacitor occurs at exceptionally high frequencies. At such exceptionally high frequencies, EMI is not attenuated by the flat-through capacitor. Because such high frequency coupling only occurs at very short-wave lengths, generally at microwave frequencies, and because the human body both reflects and absorbs microwave energy, the amount of EMI picked up by implanted leads is substantially degraded and essentially inconsequential. Accordingly, flat-through capacitors make an attractive alternative to MLCC chip capacitors as primary filter capacitors, which can be extremely helpful for AIMDs having particularly small geometries. In summary, EMI can effectively be diverted by the low k flat-through capacitor of the present application to an AIMD system ground (attenuated current i_g), the system ground being the ferrule **134** (terminal **3**) of the hermetic feedthrough, which is at the

same electrical potential as the overall electromagnetic shield (housing) of the AIMD.

FIG. **64**B is a top view of a tri-polar filter circuit board **130** having three flat-through capacitors **210"***a*, **210"***b* and **210"***c* or, alternatively, three MLCC chip capacitors **210** (not shown). FIG. **64**B illustrates on the left-hand side of each flat-through capacitor **210"**, a circuit current i_{1a} that enters at the input **178***a* (terminal **1**) of the flat-through capacitor **210"**. The leadwire positioned at **178***a* is cut off on the device side but is routed to implanted leadwires and the lead electrodes (not shown) on the body fluid side. On the right-hand side of the flat-through capacitors **210"**, the output current ilb exits at output **178***b* (terminal **2**), which is also connected to a leadwire inside the AIMD. The leadwire positioned at **178***b* projects upwardly out of the hermetic feedthrough. The leadwire layout and configuration is best understood by reviewing the cross-sectional view of FIG. **64**C.

Referring once again to FIG. **64**B, circuit current ha enters the flat-through capacitor **210"** on the left-hand side and freely passes through the flat-through capacitor exiting as circuit current i_{1b} because circuit current i_{1a}-i_{1b} comprises either biologic signals or therapeutic pacing pulses, which are low frequency circuit currents. However, at high frequencies, such as EMI RF frequencies, circuit current ha on the left-hand side **178***a* (terminal **1**) is of a relatively high amplitude, therefore, as circuit current lib exits on the right-hand side **178***b* (terminal **2**) of the flat-through capacitor **210"**, the EMI, which appears as an RF current, is substantially attenuated because the flat-through capacitor **210"** acts as a filter capacitor at high frequencies such as the EMI RF frequencies.

Referring now to FIG. **64**C, one can see that on the body fluid side of the hermetic feedthrough, the circuit current i_{1a} flows toward the device side of the hermetic feedthrough through a terminal pin **142***a* to the input **178***a* (terminal **1**) of the flat-through capacitor **210"***a*. The circuit current ha then flows through the flat-through capacitor **210"***a* and exits at the output **178***b* (terminal **2**) of said flat-through capacitor as circuit current i_{1b}. Circuit current i_{1b} then flows toward the device side of the hermetic feedthrough through terminal pin **142***a'*. Circuit current i_{1b} is then routed to the AIMD electronic circuits. The AIMD electronic circuits typically reside in or on an AIMD electronic circuit board (not shown). Any undesirable RF currents, such as an EMI RF current, are diverted (filtered) by the flat-through capacitor **210"** as attenuated current i_g to the AIMD system ground, such as ferrule **134**, which is attached to the AIMD housing **124** (not shown). Referring once again to FIG. **64**C, one will appreciate that circuit current i_1 can desirably contain therapeutic pacing pulses, which are being routed from the AIMD to implanted leads and distal electrodes or circuit current i_1 can include biological sensing frequencies, such as cardiac signals, which are being sensed by the internal circuitry of the AIMD. In other words, circuit current i_1 can flow in either direction. In addition, circuit current i_1 can undesirably contain very high EMI RF currents, which can be dangerous, even life-threatening, to a patient as previously disclosed.

FIG. **64**C further shows a method of grounding a filter circuit board, wherein the filter circuit board has at least one internal (or alternatively external) ground plate **161**. The ground plate **161** of the filter circuit board is connected to an AIMD system ground, which in FIG. **64**C is the ferrule **134** (terminal **3**) of a hermetic feedthrough **132** (not labelled). In this exemplary embodiment, illustrated on the left-hand side is a ground pin **142***gnd*, which is gold brazed **165** (or

alternatively laser welded **157**, not shown) into the ferrule **134** of the hermetic feedthrough. The terminal pin **142**gnd is shown attached in a blind via of the ferrule **134**. An alternative embodiment is shown on the right-hand size, wherein the terminal pin **142**gnd' extends through a via in the ferrule **134** to a body fluid side and a device side. The terminal pin **142**gnd, **142**gnd' of FIG. **6**C comprises an oxide-resistant material (or may alternatively comprise an oxide-resistant outer layer, such as an oxide-resistant coating, plating, or cladding) such that a very low impedance electrical connection can be made both to the terminal pin and to various via hole connections to the at least one filter circuit board ground plate **161**. Filter circuit board ground plate **161** is shown connected to six (or can alternatively be connected to "n" number) flat-through capacitor grounds (exemplary grounds **182**a, **182**b are shown in FIG. **64**B). Referring to FIG. **64**B, one will appreciate that the grounds **182**a, **182**b can be circuit board via holes or include circuit traces. What is important is that both the grounds **182**a and **182**b are conductively coupled through the circuit board via holes to the at least one ground plate **161**. This creates a multipoint grounding system, which makes flat-through capacitors very effective three-terminal filters for use in AIMDs, including filter circuit boards connected to a hermetic feedthrough of an AIMD that effectively filters EMI.

FIG. **64**D is an isometric view of a quad polar flat-through capacitor **210"**. The quad polar flat-through capacitor **210"** is similar to the unipolar flat-through capacitor of FIG. **63**, except in this case there are four active electrode plates **144** (see FIG. **64**E). As previously disclosed, circuit currents i₁ (i_{1a}-i_{1b}) pass through the active electrode plates of the quad polar flat-through capacitor of FIG. **64**D. The quad polar flat-through capacitor of FIG. **64**D also comprises a common ground plate **146** (also illustrated in FIG. **64**E). Referring once again to FIG. **64**D, each of the active electrode plates **144** has an active termination comprising active capacitor metallizations **164**a, **164**a' through **164**d,**164**d'. The ground electrode plate **146** has an edge termination comprising ground capacitor metallization **166** suitable for electrical attachment to an AIMD system ground, for example, the ferrule **134** of the hermetic feedthrough, which is attached to the housing **124** of the AIMD, the ferrule and the AIMD housing having the same electrical potential as the system ground potential.

Referring once again to FIG. **63**, one can see that there are ground connection circuit traces **182**a and **182**b. These ground circuit traces are routed to the AIMD housing **124**.

FIG. **64**F is a schematic electrical diagram of the quad polar flat-through capacitor **210"** of FIGS. **64**D and **64**E. The body fluid side is depicted on the left-hand side showing that circuit currents i_{1a} entry, which then exits as current i_{1b} on the right-hand side, which is the device side, to the AIMD circuits. When the circuit current i_{1a} is an undesirable EMI RF current, i_{1b}, is greatly attenuated (filtered). The filtering action of the flat-through filter capacitor **210"** diverts any high-frequency EMI signals as an attenuated current i_g to the AIMD system ground **124**. The attenuated current i_g is a diverter current or a filtered current, wherein any undesirable or even dangerous EMI signals are diverted or filtered to ground where such EMI signals are dissipated by the AIMD housing **124** as RF energy or heat.

FIG. **65**A is a top view (looking down on the device side of the ferrule **134**) of the quad polar flat-through capacitor **210"** of FIG. **64**D edge-mounted in a tombstone position. The edge ground capacitor metallizations **166** (not labelled) are shown electrically connected to a terminal pin **142**gnd on the left-hand side and to an oxide-resistant area **248**, **250** on

the right-hand side. These oxide-resistant ground connections is further described in FIG. **65**B. It is understood that the oxide-resistant area **248**, **250** may comprise a pocket-pad, a pocket, a pad, a metal addition or an ECA stripe. The ECA stripe is taught in U.S. provisional 62/979,600, the content of which is fully incorporated herein by this reference. The oxide-resistant area **248**, **250** may comprise a material selected from the group consisting of platinum, gold, tungsten, iridium, palladium, niobium, tantalum, ruthenium, rhodium, silver, osmium, and alloys or combinations thereof. The oxide-resistant material of the ground terminal pins **182**gnd may further be selected from the group consisting of platinum-based materials including platinum-rhodium, platinum-iridium, platinum-palladium, or platinum-gold and naturally occurring alloys such as platiniridium (platinum-iridium), iridiosmium and osmiridium (iridium-osmium). Furthermore, the electrical connection material **152** can attach directly to the gold braze **154**a of the hermetic feedthrough thereby providing an oxide resistance electrical attachment.

The tombstone mounting position refers to a filter capacitor orientation in which the ground electrode plates and the active electrode plates of the filter capacitor are positioned perpendicular to the surfaces of the ferrule and the insulator of the hermetic feedthrough. Typically, the ground and active electrode plates of a filter capacitor are aligned parallel with the body fluid side and device side surfaces of the ferrule and the insulator of the hermetic feedthrough (see FIGS. **7**, **8**, **9**, **10**, **13**, **34**, **54**, **64**B, **64**C, **70**A, **70**B, **71**B, **71**C, **72**B, **72**C, **73**, **74**A, **74**B, **74**C, **75**, **76**, **77**, **78**, **79**, **80**, **82**, **84**, **85** of the present application). In contrast, the tombstone mounting position positions the ground electrode plates and the active electrode plates perpendicular to the body fluid side and device side surfaces of the ferrule and the insulator (see FIGS. **65**A, **65**B, **65**E, **65**F, **65**I, **65**J, **65**K, **65**L, **65**M, **65**O, **65**Q, **65**R, **65**S, **65**T, **70**C and **70**D of the present application). Referring specifically to FIG. **65**A, illustrated is a device side surface **133** of the ferrule **134** and a device side surface **135** of the insulator **156**. The ground electrode plates **146** and the active electrode plates **144** of the flat-through capacitor **210"** are positioned perpendicular in relation to ferrule and insulator surfaces **133** and **135**.

Further regarding FIG. **65**A, electrical connections from the hermetic feedthrough to the AIMD circuit board and/or the AIMD circuitry can be made by one of a round wire such as **142**a of FIG. **65**A', a nail-head leadwire such as **142**b' and **142**c', a flat ribbon such as **142**d' or combinations thereof. These are only exemplary connection options, as there are various other ways of connecting to an AIMD circuit board and/or AIMD circuitry (not shown), including directly abutting the circuit board to terminations and making a direct electrical connection. Also, a connection to flexible circuit boards or at least a portion of a flexible circuit board can be done. Any of the electrical connections previously disclosed in U.S. Pat. No. 8,195,295 can also be incorporated into the embodiments of the present application. Accordingly, the content of U.S. Pat. No. 8,195,295 is fully incorporated herein by this reference.

FIG. **65**B is a cross-sectional view taken from section **65**B-**65**B of FIG. **65**A. The insulator **156** of the hermetic feedthrough comprises various feedthrough conductive paths **129**. For example, an embodiment on the far left-hand side of the hermetic feedthrough illustrates a conductive path comprising a nail-head leadwire **142**a, which can alternatively be just a plain leadwire. Another embodiment to the right of far left-hand side embodiment comprises a co-sintered past-filled via comprising a ceramic reinforced

composite (CRMC) **185** and platinum caps **187**. Next, to the right of the embodiment just disclosed is another a co-sintered past-filled via embodiment comprising a platinum core **187** surrounded by a CRMC outer layer **185**. It is appreciated that, alternatively, the entire co-sintered via can comprise just an essentially pure co-sintered platinum paste-filled via without any CRMC. On the far right-hand side is another co-sintered past-filled via embodiment comprising a dumbbell shape formed by the combination of the platinum **187** and the CRMC **185** materials. The embodiments of the feedthrough conductive paths **129** of the hermetic feed-through of FIG. **65**B are exemplary only and may comprise variations thereof. For example, the feedthrough conductive pathway **129** may be selected from the group consisting of a terminal pin, a pin, a leadwire, a lead wire, a two-part pin, a lead conductor, a sintered paste-filled via, a co-sintered via, a co-sintered paste-filled via, a co-sintered via with one or more metallic inserts, or combinations thereof. The feed-through conductive pathway **129** may comprise the same embodiment for all feedthrough conductive pathways of the hermetic feedthrough, or alternatively may comprise at least one different feedthrough conductive pathway of the total feedthrough conductive pathways of the hermetic feed-through.

Referring again to FIG. **65**B, two methods of grounding the flat-through capacitor is shown. On the right-hand side, the electrical connection material **152** is shown attached to an oxide-resistant area **248**, **250**. The oxide-resistant area may comprise a pocket, a pad (for example, a gold pocket or a gold pad), a metal addition or an ECA strip. Gold pockets and gold pads are more thoroughly described in U.S. Pat. No. 10,350,421, the content of which is fully incorporated herein by this reference. On the left-hand side, the ground capacitor termination **166** of the flat-through capacitor is shown connected to an oxide-resistant terminal pin **142**gnd. The oxide-resistant terminal pin **142**gnd is attached to the ferrule **134** either by a gold braze **165** or a laser weld **157** (not shown), as previously disclosed. It is understood by those skilled in the art that the electrical connection on the right-hand side can alternately comprise an electrical con-nection material **152** connected to an ECA stripe or to the gold braze **154**a of the hermetic feedthrough for an essen-tially oxide-free electrical attachment.

FIG. **64**C further shows a method of grounding a filter circuit board, wherein the filter circuit board has at least one internal (or alternatively external) ground plate **161**. The ground plate **161** of the filter circuit board is connected to an AIMD system ground, which in FIG. **64**C is the ferrule **134** (terminal **3**) of a hermetic feedthrough **132** (not labelled). In this exemplary embodiment, illustrated on the left-hand side is a ground pin **142**gnd, which is gold brazed **165** (or alternatively laser welded **157**, not shown) into the ferrule **134** of the hermetic feedthrough. The terminal pin **142**gnd is shown attached in a blind via of the ferrule **134**. An alternative embodiment is shown on the right-hand size, wherein the terminal pin **142**gnd' extends through a via in the ferrule **134** to a body fluid side and a device side. The terminal pin **142**gnd, **142**gnd' of FIG. **6**C comprises an oxide-resistant material (or may alternatively comprise an oxide-resistant outer layer, such as an oxide-resistant coat-ing, plating, or cladding) such that a very low impedance electrical connection can be made both to the terminal pin and to various via hole connections to the at least one filter circuit board ground plate **161**. Filter circuit board ground plate **161** is shown connected to six (or can alternatively be connected to "n" number) flat-through capacitor grounds (exemplary ground circuit traces **182**a, **182**b are shown in

FIG. **64**B). Referring to FIG. **64**B, one will appreciate that the ground circuit traces **182**a, **182**b can be circuit board via holes or include circuit traces. What is important is that both the ground circuit traces **182**a and **182**b are conductively coupled through the circuit board via holes to the at least one ground plate **161**. This creates a multipoint grounding sys-tem, which makes flat-through capacitors very effective three-terminal filters for use in AIMDs, including filter circuit boards connected to a hermetic feedthrough of an AIMD that effectively filters EMI.

FIG. **65**C is another type of quad polar flat-through capacitor **210**"int which is an internally grounded flat-through capacitor. Internally grounded capacitors are more thoroughly described in U.S. Pat. No. 5,905,627, the content of which is fully incorporated herein by this reference. Referring to the internally grounded flat-through capacitor of FIG. **65**C, the ground electrode plates **146** do not extend to the edges of the flat-through capacitor **210**", but instead connect, as shown in FIG. **65**D, to either two ground capacitor metallization areas **166** (not shown) or to a con-tinuous ground capacitor metallization stripe **166** as shown in FIG. **65**C.

FIG. **65**D is a sectional view taken from section **65**D-**65**D of FIG. **65**C illustrating the active electrode plates **144**a through **144**d and the ground electrode plates **146** of the flat-through capacitor of FIG. **65**C.

FIG. **65**E shows the top view of a device side internally grounded flat-through capacitor **210**"int FIGS. **65**C and **65**D edge-mounted in a tombstone position. As illustrated, the flat-through capacitor **210**"int at least partially shields the open windows of the insulator **156**. The term "open win-dows" refers to an area that is not shielded such that dangerous EMI fields can enter and radiate through. The internally grounded flat-through capacitor **210**" mounted to a hermetic feedthrough as shown in FIG. **65**E works simi-larly to the door of a microwave comprising a metal plate perforated with holes. As microwave ovens, for conve-nience, have a glass window so one can watch the food being cooked, the holes of the metal plate encased by the glass window comprises a calculated hole diameter such that the perforated metal plate becomes a wave guide having wave beyond cutoffs so that dangerous microwave energy used to cook the food cannot get through the holes of the metal plate. Just as the perforated metal plate of the microwave door effectively shields at least a portion of the microwaves from escaping from the oven to the outside where one is watching the food cook, so too does the internally grounded flat-through capacitor **210**"int and its associated ground elec-trode plates effectively shield at least a portion of the open windows of the insulator **156** of the hermetic feedthrough from letting undesirable EMI into the device side (inside) of the housing of an AIMD. As such, it is therefore not necessary that the open windows of the insulator **156** be completely shielded, as evidenced by everyday microwave ovens. Accordingly, the design of FIG. **65**E carefully accounts for the width of the insulators **156** and the width of the flat-through capacitor **210**"int, such that, any EMI that can undesirably couple, cannot pass through. In other words, the internally grounded flat-through capacitor provides suf-ficient shielding of the hermetic feedthrough such that the open window portions act as effective wave guides having beyond cutoffs to prevent dangerous EMI entry into the device side of an AIMD.

FIG. **65**F is a cross-sectional view taken from section **65**F-**65**F of FIG. **65**E. One can see that the flat-through capacitor **210**"int is no longer connected directly to the ferrule **134** as shown in FIG. **65**B. Instead, at the center, the

capacitor ground electrode plates **146** are connected to the ground capacitor metallization **166'**. There is an electrical connection material **151** that connects between the ground capacitor metallization **166'** and a peninsula **139** or bridge **141** of the ferrule **134**. Peninsulas and bridges are more thoroughly disclosed in U.S. Pat. No. 6,765,780, the content of which is fully incorporated herein by this reference. On the device side, nail-head leadwires **142a'** through **142d'** are shown. It is appreciated that the previously described round wires, flat ribbons, or other types of connections can alternatively be used.

FIG. **65**G illustrates a hybrid flat-through capacitor **210"**hyb. This hybrid design comprises edge ground capacitor metallizations **166** and a center ground capacitor metallization **166'** as shown.

FIG. **65**H is a sectional view taken from section **65**H-**65**H of FIG. **65**G illustrating the active electrode plates **144a** through **144d** and the ground electrode plates **146** of the flat-through capacitor of FIG. **65**G. Referring now to FIG. **65**H, the quad polar active electrode plates **144a** through **144d** each respectively connect to an active capacitor metallization **164a** through **164d** of the flat-through capacitor **210"**hyb, as indicated. The flat-through capacitor **210"**hyb also comprises ground capacitor metallizations, the ground capacitor metallizations comprising an edge ground capacitor metallization **166** on the left-hand side and the right-hand side of the flat-through capacitor and a ground capacitor metallization **166'** positioned in the center of the flat-through capacitor. The ground electrode plates **146** are electrically connected externally to the edge ground capacitor metallizations **166** on the left-hand and right-hand sides of the flat-through capacitor and internally to the center ground capacitor metallization **166'** thereby forming the hybrid filter flat-through capacitor **210"**hyb. It is noted that there can be a multiplicity of internal ground capacitor metallizations **166'**, which can be particularly important for longer flat-through capacitors, as increasing the number of internal ground metallizations in a substantially longer flat-through capacitor acts to keep the inductance of the longer flat-through capacitor low.

FIG. **65**I illustrates a hybrid filter flat-through capacitor **210"**hyb edge-mounted in a tombstone position to a device side of a hermetic feedthrough **132** (not labelled). One can see that there are nail head terminal pins **142a'** through **142d'** that are connectable to AIMD electronics, such as an AIMD active electronic circuit board (not shown). The hybrid filter flat-through capacitor **210"**hyb is shown grounded at the right-hand side to an oxide-resistant area **248, 250** using electrical connection material **152**. It is understood that the oxide-resistant area **248, 250** may comprise a pocket, a pad (for example, a gold pocket or a gold pad), a metal addition or an ECA stripe. An electrical connection can also alternatively comprise a direct connection to at least a portion of gold braze **154a**. At the left-hand side, shown is a ground electrical connection electrically connecting an end ground capacitor metallization **166** to a ground terminal pin **142**gnd using electrical connection material **152**. The ground terminal pin **142**gnd at the left-hand side is shown gold brazed or welded to the ferrule **134** of the hermetic feedthrough **132**. At the center of the hybrid filter flat-through capacitor **210"**hyb, an internal ground connection to an oxide-resistant area **248, 250** is also shown. The ferrule **134** of the hermetic feedthrough of FIG. **65**I comprises either a peninsula **139** or a bridge **141**, the peninsula or the bridge being integrally formed as a continuous part of the ferrule **134**. As defined herein, a peninsula **139** partially extends inwardly into a ferrule opening **131** and a bridge **141** extends completely

across a ferrule opening **131** (not labelled). A device side ground terminal pin **142**gnd extends through a capacitor conductive passageway (a capacitor via hole) of the capacitor dielectric body **148** (not labeled). The ground terminal pin **142**gnd is conductively and mechanically connectable to one of the peninsula **131** and the bridge **141** of the ferrule **134** of the hermetic feedthrough. As previously disclosed, the hybrid filter flat-through capacitor **210"**hyb may comprise either a single internal ground connection or alternatively multiple internal ground connections. It is desirable that the hybrid filter flat-through capacitor **210"**hyb have a multiplicity of ground plates, the multiplicity of ground plates being oriented in a tombstone position such that the hybrid filter flat-through capacitor **210"**hyb at least partially shields radiated EMI from penetrating directly through any open windows of the insulator **156** of the hermetic feedthrough. It is appreciated that the insulator **156** can be a single insulator or comprise two or more separate insulators, such as shown in FIG. **65**I. Again, it is important that the design qualification of a filtered feedthrough **122**, such as illustrated in FIG. **65**I, include wave guide calculations and suitable filter performance testing, including insertion loss at high frequency to assure EMI is effectively attenuated. It is also extremely important that, for all new EMI filter capacitor designs, filter capacitor insertion loss and attenuation be measured at various frequencies. Ideally, these measurements should be swept measurements using a network or spectrum analyzer. A critical capacitor EMI filter performance metric is its insertion loss, which is measured in decibels (dB). Measurements of capacitance, ESR, insulation resistance and dielectric withstanding voltage are other valuable capacitor measurements, however, these measurements do not directly measure the RF performance of a filter capacitor. As such, it is critical that the insertion loss characteristics of every new EMI filter capacitor design be thoroughly evaluated at least as a part of the initial qualification of the product and the insertion loss specified to ensure EMI attenuation is effectively achieved, thereby preventing undesirable and potentially AIMD therapy delivery malfunctions from occurring.

FIG. **65**J is a cross-sectional view taken from section **65**J-**65**J of FIG. **65**I showing a filtered feedthrough **122** comprising the hybrid filter internally grounded flat-through capacitor **210"**hyb attached to a hermetic feedthrough **132** (not labelled). Illustrated is quad polar hybrid filter flat-through capacitor **210"**hyb comprising an internal ground connection at its center **166'** and edge ground connections at its two end ground capacitor metallizations **166**. Such a hybrid filter ground connection is important if the flat-through capacitor gets very long, as it is not desirable that the active electrode plates be located distant from the system ground. The hybrid ground connection of the present application is also known as a multipoint grounding system, which guarantees highly effective EMI filter performance at high frequencies. Another way of looking at this is that multipoint grounding does not allow too much inductance to build up across the critical ground electrode plates **146**.

As previously described, the edge ground capacitor metallizations **166** of the hybrid filter flat-through capacitor **210"**hyb can be connectable to an oxide-resistance area **248, 250**, such as a pocket, a pad, a conductive stripe, or even a hermetic braze of the hermetic feedthrough, which is shown on the right-hand side of FIG. **65**J. The oxide-resistant area of FOG. **65**J is attached to the ferrule **134** of the hermetic feedthrough of the filtered feedthrough **122**. The oxide-resistant area **248, 250** may comprise a gold pocket, a gold pad, a noble metal addition, for example, a metal addition

comprising platinum, gold, palladium, or alloys thereof, an ECA stripe attached to a noble metal area of a ferrule, such as a noble metal laminated foil, a metallization, a vapor deposited film, a plating, or a coating, or combinations thereof. An electrical connection material **152** is used to make such electrical connections to the oxide-resistance area **248**, **250**. It is understood by those skilled in the art that an oxide-resistant attachment can also be made to the gold braze **154**a of the hermetic feedthrough.

On the left-hand side of the hybrid filter flat-through capacitor **210"hyb** of FIG. **64J** is an oxide resistant ground terminal pin **142gnd**. The oxide-resistant ground terminal pin **142gnd** may be attached to the ferrule **134** of the hermetic feedthrough **132** (not labelled) by either a gold braze or a laser weld; however, other joining methods can be used to attach the oxide-resistant ground terminal pin **142gnd**, including micro-welding, micro-TIG welding, ultrasonic welding, resistance welding, friction welding, butt welding, arc welding, gas welding, projection welding, flash welding, upset welding, solid state welding, diffusion welding, induction welding, percussion welding, electron beam welding, multi-stage brazing, or reactive brazing. While the oxide-resistant ground terminal pin **142gnd** on the left-hand side of FIG. **64J** is shown attached in a blind via of the ferrule **134**, alternatively, the oxide-resistant ground terminal pin **142gnd** can pass all the way through a via hole of the ferrule **134** of the hermetic feedthrough as previously disclosed in FIG. **64C**. It will also be understood by those skilled in the art that an insulator washer **162** typically resides between the hybrid filter flat-through capacitor **210"hyb** and the insulator **156** of the hermetic feedthrough. It will also be understood that the insulator washer **162** will also similarly reside in all of the filtered feedthroughs **122** of the present application having filter capacitors attached to the insulator **156** of the hermetic feedthrough. It is noted that, for simplicity, the insulator washer of the figures of the present application is not cross-hatched.

FIG. **65Ja** is generally taken from section **65Ja-65Ja** of FIG. **65J** illustrating an embodiment comprising a ground terminal pin **142gnd** passing all the way through the ferrule **134** of a hermetic feedthrough. The ground terminal pin **142gnd** can be electrically and hermetically attached to the ferrule **134** by a gold braze **165** or a laser weld **157** or any of the joining methods previously disclosed.

FIG. **65Jb** is generally taken from section **65Jb-65Jb** of FIG. **65J** illustrating an embodiment of an oxide-resistant area **248**, **250** having a metallization layer **225** overlaid by an electrically conductive adhesive (for example an ECA stripe or an ECS dot) **223**. ECA stripes over metallization layers are more thoroughly described in U.S. provisional 62/979,600, the content of which is fully incorporated herein by this reference. In the embodiment of FIG. **65Jb**, the electrical connection material **152** contacts at least a portion of the ECA stripe **223**. The electrical connection material **152** is also shown contacting a portion of the ferrule **134**, however, the connection to the ferrule is not required as the ferrule **134**, if made of an easily oxidizable material, such as titanium, can heavily oxidize as previously disclosed.

Further regarding titanium, it is generally understood that: 1) titanium has a great chemical affinity for combining with oxygen; and 2) titanium does not have a great affinity for combining with any other chemicals. It is generally understood that, in open air, freshly machined or cleaned titanium quickly forms a layer of oxides. This formation of oxides creates a natural passivity that inhibits reactions with other chemicals, such as salt or oxidizing acid solutions. The result is that titanium has superior corrosion resistance. However,

titanium oxide layers can be present on a titanium ferrule at the time an electrical connection material is applied. Even if titanium oxide layers are removed prior to applying electrical connection material, the titanium can re-oxidize later on. For example, during laser welding of the ferrule **134** to the AIMD housing **124**, substantial localized heat may be generated, which can accelerate titanium oxide layer formation. The industry generally believes that titanium oxide layers will not form on titanium components internal the AIMD housing once hermetically sealed, mostly because AIMDs can be assembled in or back-filled with an inert gas, such as helium, nitrogen or argon. The industry typically does so with the intent of inhibiting oxidation of sensitive metals like titanium. This belief is erroneous. Materials of construction used in the manufacture of AIMDs, such as polymers, plastics, adhesives, elastomers and the like, and even the printed circuit boards (PCBs) themselves inside the AIMD housing, generally have some level of gases trapped within their structures, for example, moisture, oxygen, other oxygen-containing gases, or even undetected residues comprising same, that eventually outgas during the operating life of the AIMD. Furthermore, processes that can involve increased temperature like welding, curing or heat treatment processes, or even actions having temperature shifts, such as are possible during shipping, can accelerate such outgassing. Hence, even if an AIMD is manufactured in an inert gas environment, or backfilled with an inert gas, such 'heating' of certain materials of construction can release oxygen, oxygen-containing gases or water vapor into an otherwise hermetically sealed environment causing the formation of oxide layers on easily oxidizable materials like titanium. The formation of such an oxide layer increases the RF ground impedance, which seriously degrades EMI filter performance. Moreover, even when titanium is heated during welding, titanium oxides form even faster, and as the temperature reaches titanium's melting point (1,668° C., 3034° F.), the oxides typically dissolve into solution and can contaminate the weld pool, which can cause an impure and/or a weak weld. This is why special care is generally taken to minimize exposure of titanium components to oxygen during welding, such as employing a shield gas, for example, argon or helium, or welding in a full vacuum (as is the case with electron beam welding). Regardless, welding, even laser welding as typically used by AIMD manufacturers, can cause heating along the weld seam of the AIMD, which may also involve heating of the device side ferrule surface as well. Hence, it is conceivable that when exposed to such heating by laser welding, the titanium ferrule **134**, and in particular the device side ferrule surface, can undesirably re-oxidize. The inventors studied the effect of titanium oxides on feedthrough filters, measuring ESR/insertion loss (IL) pre- and post-laser welding. The inventors observed that post-laser welding, the ESR measurements of some feedthrough filters of a very large lot increased from the pre-laser welding measurement by orders of magnitude. To this day, when attachment is made directly to titanium or other oxidizable metal without the presence of an oxide-resistant intermediary between the titanium and the electrical attachment material, the inventors have found that, while most parts in a production lot remain within ESR/IL specification post-laser welding, there consistently are some parts in this same lot that fail ESR/IL horribly. Thus, since failing ESR measurements remain unpredictable even under protective laser welding protocols, attaching to an ECA stripe without an oxide-resistant intermediary is a highly undesirable practice. Accordingly, the generally accepted belief that a titanium oxide layer will not form on titanium components

internal an AIMD housing once hermetically sealed simply because AIMDs can be assembled in or back-filled with an inert gas is flawed and inaccurate. Thus, electrically connecting to an easily oxidizable material such as titanium, more particularly, the deposition of an ECA stripe, without an intermediary oxide-resistant area **248**, **250** is highly undesirable, as such electrical connections have proven to be a highly unreliable due to re-oxidation and related increasing resistance. For more detail referring to the effects of oxide layer formation on EMI filtering, refer to the paper entitled, "Dissipation Factor Testing is Inadequate for Medical Implant EMI Filters and Other High Frequency MLC Capacitor Applications", ISSN: 0887-7491, presented at CARTS 2003: 23rd Capacitor and Resistor Technology Symposium, Mar. 31-Apr. 3, 2003, the content of which is fully incorporated herein by this reference.

FIG. **65Jc** is taken from section **65Jc-65Jc** of FIG. **65J**. In this embodiment, a metal addition **159** is shown welded **229** to the ferrule **134**. There are various methods of attaching metal additions to the ferrule, which are more thoroughly disclosed in U.S. Pat. No. 9,931,514, the content of which is fully incorporated herein by this reference. The electrical connection material **152** must contact at least a portion of the metal addition **227** as shown to form a reliable oxide-resistant electrical connection.

FIG. **65Jd** is very similar to FIGS. **65Ja** through **65Jc**, except that in this embodiment, the electrical connection material **152** at least partially contacts a gold braze **154**a. Electrical connection to the gold braze of a hermetic feedthrough is disclosed in U.S. Pat. No. 6,765,779, the content of which is fully incorporated herein by this reference.

Referring once again to FIGS. **65J**, **65Ja** through FIG. **65Jd**, it is appreciated that any of the filter capacitors of the present application can be grounded in a like manner.

FIG. **65K** is very similar to FIG. **65I** illustrating a top view of an embodiment of a hybrid filter flat-through capacitor **210"hyb** mounted in a tombstone position, except that instead of the bridge **141** of the ferrule **134** of the hermetic feedthrough, a peninsula **139** is shown. As previously disclosed, the hybrid filter flat-through capacitor **210"hyb** at least partially effectively blocks direct penetration of EMI through the insulator **156** of the hermetic feedthrough. Additionally, the insulator **156** of FIG. **65I** not a single insulator as is the insulator **156** of FIG. **56K**. The insulator **156** of FIG. **65K** is modified to accommodate the peninsula **139**. The hybrid filter flat-through capacitor **210"hyb** is a three-terminal capacitor, as are hybrid feedthrough filter capacitors. Hybrid feedthrough filter capacitors are disclosed in U.S. Pat. No. 6,765,780, the content of which is fully incorporated herein by this reference. As previously disclosed, the ferrule **134** of the hermetic feedthrough of the filtered feedthrough **122** can comprise "n" number of peninsulas **139** so that a multipoint grounding system can be created. Referring to FIG. **65K**, similar to the hybrid feedthrough filter capacitor of the '780 patent, grounding of the hybrid filter flat-through capacitor **210"hyb** comprises electrical connections of at least one edge ground capacitor metallization **166** and at least one internal ground capacitor metallization **166'** (or internal ground connection). Shortening the bridge, as taught by the '780 patent, is a simple variation of just shortening up the bridge to make said bridge a peninsula. An advantage of shortening up the bridge to make a peninsula is that the hermetic feedthrough requires only one insulator **156**, which can be gold brazed **154**a in a single operation to the ferrule **134** of the hermetic feedthrough.

Referring once again to FIG. **65K**, electrically connecting the active capacitor metallization **164**a through **164**d and **164'**a through **164'**d to the respective terminal pins **142**a through **142**d and **142'**a through **142'**d is best illustrated in FIG. **65L** and FIG. **65M**. FIG. **65L** is a side view **65L-65L** of FIG. **65K** illustrating the active capacitor metallizations **164**a through **164**d and **164'**a through **164'**d connected with respective terminal pins **142**a through **142**d and **142'**a through **142'**d using an electrical connection material **145**. The active capacitor metallizations of the hybrid filter flat-through capacitor **210"hyb** partially extend along the surface of the side of the filter capacitor as shown, in order to secure the terminal pins to the filter capacitor in a mechanically and electrically robust manner. In other words, attachment of the terminal pins to the extended active capacitor metallization increases the bonding area of the electrical connections providing secure attachment that sustains mechanical shock and vibration. Referring once again to FIG. **65L**, it is appreciated that the active capacitor metallizations **164**a through **164**d and **164'**a through **164'**d must wrap over the edge of the thickness of the hybrid filter flat-through capacitor **210"hyb**, which is shown at the top and the bottom of the tombstone mounted capacitor so that electrical connection of the active electrode plates of said hybrid filter capacitor are made. Also illustrated in FIG. **65L** are edge ground capacitor metallizations **166** and at least one internal ground capacitor metallization **166'** (shown in the center of the hybrid filter capacitor). The internal ground capacitor metallization **166'** must also wrap over the edge of the thickness of the hybrid filter flat-through capacitor **210"hyb** at the top and the bottom of the tombstone mounted capacitor for proper connection to the hybrid filter capacitor's ground electrode plates **146**. An electrical connection material **152** connects the hybrid filter capacitor edge ground capacitor metallization **166** on the right-hand side to the ferrule surface **133** and to an oxide-resistant ground terminal pin **142gnd** on the left-hand side. Electrical connection to the ferrule surface **133** on the right-hand side can be made using any one of the oxide-resistant area **148**, **150** embodiments of FIGS. **65J**, **65Ja** through **65Jd**. Electrical connection can alternatively be made by a direct connection to a gold braze **154**a.

FIG. **65M** is the opposite (reverse) side view taken from section **65M-65M** of FIG. **65K**. In this view, one can see the centered internal ground terminal pin **142gnd**. The ground terminal pin **12gnd** is conductively and mechanically connected to at least one of a peninsula **139** or a bridge **141** of the ferrule **134** of the hermetic feedthrough. The centered internal ground terminal pin **142gnd** is either gold brazed or welded to the peninsula **139** or to the bridge **141** of a ferrule structure **134**. Importantly, the ground terminal pin **142gnd** provides a very low resistance and low impedance electrical connection to the hybrid flat-through capacitor grounding system **210"hyb** so that high frequency RF energy can be diverted to the ferrule and then, in turn, to the AIMD housing (not shown). It is appreciated that all the ferrule structures described herein are configured to be laser welded into an opening of the housing of an AIMD.

FIG. **65N** is a top view of an embodiment of a hermetic feedthrough **132**. Shown are six active terminal pins **142**a through **142**f, which alternatively may be co-sintered paste-filled vias. As illustrated, the active terminal pins **142**a through **142**f pass through the insulator **156** of the hermetic feedthrough **132** in non-conductive relationship with the ferrule **134**. On the left-hand side of FIG. **65N**, an oxide-resistant area **248** is shown, which in FIG. **65N** may be a circular gold pocket-pad. It is understood that the gold pocket-pad may be any shape, including a circle, a rectangle,

a square, an oval, a custom designed shape, or any shape commensurate with the needs of an application. Alternatively, the gold pocket-pad can instead be an ECA stripe as previously disclosed. An ECA stripe overlays an oxide-resistant metallized area as disclosed in U.S. provisional 62/979,600. On the right-hand side of FIG. **65**N, shown is a ground terminal pin **142**gnd. The ground terminal pin **142**gnd is either gold brazed **165** or welded **229** directly to the ferrule **134** and comprises an oxide-resistant material such as previously disclosed. Both the right-hand and left-hand sides of the insulator **156** are curved, but can alternatively be a rectangular shape, which simply means that the ground locations are moved further out. In other words, the shape of the insulator can take on any shape that is required for an application. Referring once again to FIG. **65**N, illustrated is what is known as a dual inline staggered pin feedthrough terminal pin layout.

FIG. **65**O is an isometric view of a dual inline hybrid filter flat-through capacitor **210**″hyb. One can see on the far left-hand side of the hybrid filter flat-through capacitor **210**″hyb that there is a first ground capacitor metallization **166** on the very top of the dielectric body **148** of said filter capacitor, while on the right-hand side of the hybrid filter flat-through capacitor **210**″hyb there is a second ground capacitor metallization **166** at the very end of the dielectric body **148** of said filter capacitor. Visible are also six active capacitor metallizations **164**a' through **164**f on the top surface of the dielectric body **148** of the hybrid filter flat-through capacitor **210**″hyb. There are also six corresponding active capacitor metallizations **164**a through **164**f on the bottom side of the dielectric body **148** of the hybrid filter flat-through capacitor **210**″hyb that are not visible.

FIG. **65**P is an isometric view of the hybrid filter flat-through capacitor **210**″hyb of FIG. **65**O illustrating the active electrode plates **144**a through **144**f and the ground plates **146** residing within the dielectric body **148** of said filter capacitor. In the embodiment shown, each active electrode plate **144**a through **144**f is sandwiched between a pair of ground electrode plates **146**. Each active electrode plate **144**a through **144**f is electrically connected to its respective active capacitor metallization **164**a' through **164**f'. Each ground electrode plate **146** is electrically connected to the left-hand side and the right-hand side ground capacitor metallizations **166**. It is noted that, while the first ground capacitor metallization **166** on the left-hand side is disposed on the top of the hybrid filter flat-through capacitor **210**″hyb and the second ground capacitor metallization **166** on the right-hand is disposed on the end of said filter capacitor, the ground capacitor metallizations **166** can be positioned reversely, meaning the left-hand side can be an end ground capacitor metallization and the right-hand side can be a top ground capacitor metallization. Likewise, both ground capacitor metallizations can be top ground capacitor metallizations or, alternatively, both can be end ground capacitor metallizations. It is also understood that although just one active electrode plate is shown for connection to a feedthrough leadwire, in practice, multiple "n" number of active electrode plates and ground electrode plates can be electrically connected to each feedthrough leadwire.

FIG. **65**Q is a top view of the dual inline hybrid filter flat-through capacitor **210**″hyb of FIGS. **65**O and **65**P mounted on a hermetic feedthrough **132** (not labelled). The capacitor shown has a ground connection at the left-hand side and the right-hand side of the ferrule **134** of the hermetic feedthrough. The ground connections are better understood in the cross-section of FIG. **65**R. As can be seen in FIG. **65**Q, there are six active capacitor metallizations

164a' through **164**f' (not labelled), hence the hybrid filter flat-through capacitor **210**″hyb is a hex-polar three-terminal hybrid filter capacitor. Also shown in this top view are the active terminal pins **142**a' through **142**f. Terminal pins **142**a' through **142**d' are nail head terminal pins, the nail head being suitable for attachment to the active capacitor metallizations **164**a' through **164**d' (not labelled) of the hybrid filter flat-through capacitor **210**″hyb using an electrical connection material **151**. Terminal pins **142**e' and **142**f' are lying sideways on their respective active capacitor metallizations **164**e' and **164**f' (not labelled) and are attached to said metallizations using an electrical connection material **145**. It is appreciated that these terminal pins can be round wires, flat ribbon, wire bonding cables, leadwires, lead wires, pins, lead conductors or similar as previously disclosed. Alternatively, the electrical connection to the active capacitor metallizations can even be made to an AIMD active electronic circuit board butted up directly to and mating with said active capacitor metallizations without the need for a lead-wire interconnection. The dual inline hybrid filter flat-through capacitor **210**″hyb of FIG. **65**Q is wide and completely covers the entire surface of the insulator **156** of the hermetic feedthrough. As such, waveguide calculations are unnecessary because the ground electrode plates of the hybrid filter flat-through capacitor **210**″hyb completely shield any open windows mitigating any threat of direct penetration by electromagnetic interference radiation through the insulator **156**.

FIG. **65**R is a cross-sectional view taken from **65**R-**65**R of FIG. **65**Q. Shown is the active electrode plate **144**a associated with the terminal pin **142**a'. It is appreciated that in practice multiple active electrode plates ("n" number of active electrode plates **144**) are interleaved with ground electrode plates **146** sandwich style.

FIG. **65**S is taken from **65**S-**65**S of FIG. **65**Q. Shown is one of the multiplicity of interleaved ground electrode plates **146**. A variety of grounding methods for the ground electrode plate **146** and associated ground capacitor metallizations **166** are shown. On the left-hand side, an oxide-resistant area **248**, **250** (such as a gold pocket or a gold pad) is used to provide electrical connection to the ferrule **134** of the hermetic feedthrough. On the right-hand side, a ground terminal pin **142**gnd that is either gold brazed **165** or welded **229** to the ferrule **134** is used to provide electrical connection to the ferrule **134** of the hermetic feedthrough. Alternatively, an electrical connection material may be used on the right-hand and the left-hand sides to contact a gold braze **154**a to achieve the oxide-resistant electrical connection. Referring once again to FIG. **65**S, one can see that active terminal pins **142**b' and **142**d' comprise nail-head structures, which can be attached by BGA **151** or similar mounting methods to the active capacitor metallizations **164** (not labelled). Active terminal pins **142**e' are longitudinally aligned in parallel with the surface of the active capacitor metallizations using electrical connection material **145** as shown. Such parallel alignment is desirable for a higher surface area attachment, which is generally more resistant to shock and vibration loads. Terminal pin **142**e' illustrates a round wire and terminal pin **142**f' illustrates a flat ribbon, both of which can be attached to the active capacitor metallization by an electrical attachment material **145** as shown or, alternately, by other industry methods such as wire bonding or ultrasonic bonding.

FIG. **65**T is taken from **65**T-**65**T of FIG. **65**Q. Illustrated is an active electrode plate **144**b that is associated with terminal pin **142**b'. It is understood that all of the figures illustrating filtered feedthrough **122** typically comprise an

insulation washer **162** disposed between the flat-through capacitor **210"**hyb and the device sides of the insulator **156** and the ferrule **134** as illustrated in the exemplary embodiments of FIG. **65**T. The insulating washer **162** provides a mechanical attachment to at least one of the ferrule **134** and the insulator **156**, while, at the same time, said insulating washer insulates the terminal pins one from the other; for example, the insulating washer **162** insulates between two active terminal pins and also insulates between an active terminal pin and a ground connection, such as between an active terminal pin and a ground terminal pin. The insulation washer **162** is important because it prevents high voltage flashover, such as is possible in an implantable defibrillator application, and also inhibits undesirable migration of materials, which can lead to reduced insulation resistance between adjacent circuits (channels) or any of the active circuits and ground. It is noted that, for simplicity, the insulator washer **162** of the figures of the present application is not cross-hatched.

FIG. **66** illustrates a bipolar X2Y attenuator **210"**, bipolar meaning that the X2Y attenuator **210'''** can filter two leadwires at the same time. This is better understood by examining the internal active electrode plates **144**a and **144**b of FIG. **67**. The active electrode plates **144**a are connected to the left-hand side active capacitor metallization **164**a. The right-hand side active electrode plates **144**b are connected to the right-hand side active capacitor metallization **164**b. The active electrode plates are interleaved with the ground electrode plates **146** of FIG. **68**. This interleaved configuration is illustrated in FIG. **69**, showing that active electrode plates **164**a and **164**b are both interleaved with a plurality of ground electrode plates **146**. It is appreciated that any number of active and ground electrode plates can be interleaved to create a desired line-to-line or a line-to-ground amount of capacitance or filtering. For example, if one wanted a great deal of line-to-line filtering, that is, filtering between active capacitor metallizations **164**a and **164**b, then one eliminates the interleaved ground electrode plate **146**, which thus increases the effective capacitance area (ECA) between these two opposed active electrode plates. However, if one wanted mostly line-to-ground filtering, in other words, filtering from active capacitor metallization **164**a to ground capacitor metallization **166** and active capacitor metallization **164**b to ground capacitor metallization **166**, then one interleaves ground electrode plates **146** as illustrated in FIG. **69**.

FIG. **69**B is similar to FIG. **66** except that instead of the discontinuous discrete ground capacitor metallizations **166**a and **166**b of FIG. **66**, a continuous ground capacitor metallization **166** is illustrated. The continuous ground capacitor metallization **166** of the X2Y attenuator **210'''** is a metallization band disposed all the way around said X2Y attenuator. Either of the ground capacitor metallization embodiments of FIGS. **66** and **69**B can be used for the X2Y attenuator **210'''** as the ground electrode plates **146** shown in both FIGS. **66** and **69** are configured to selectively extend to the edge of each long side of the dielectric body of the X2Y attenuators. The selective extension of the ground electrode plates allows contact to be made to either ground capacitor metallization embodiment. The ground electrode plate edge extensions are illustrated in the discontinuous discrete ground capacitor metallizations **166**a and **166**b of FIGS. **68** and **69** and in the continuous ground capacitor metallization **166** of FIG. **69**C. In summary, the selective extensions of the ground electrode plates **146** at the edge of the long sides of the dielectric body of the X2Y attenuator contacts the ground capacitor rnetallization(s) of said X2Y attenuator

regardless of whether said ground capacitor metallization comprises a continuous ground capacitor metallization band as illustrated in FIG. **69** or discontinuous discrete ground capacitor metallization bands as illustrated in FIG. **66**.

FIG. **69**C is a sectional view illustrating the active electrode plates **144**a, **144**b and the ground electrode plate **146** that interleave the X2Y attenuator of FIG. **69**B. The X2Y attenuator **210'''** looks similar in physical appearance to the flat-through capacitors **210"** previously disclosed, however, the X2Y attenuators of FIGS. **66** and **69**B are unique bipolar devices that can filter two leadwires of the hermetic feedthrough at the same time. Simultaneous filtering of two feedthrough leadwires is possible because the active electrode plates Ca and Cb of the X2Y attenuators FIGS. **66** and **69**B are designed such that the X2Y attenuator essentially comprises two different capacitors, one capacitor comprising the active electrode plates Ca electrically connected to an active capacitor metallization **164**a and a second capacitor comprising the active electrode plates Cb electrically connected to an active capacitor metallization **164**b. Each active electrode plate **164**a, **164**b is sandwiched by ground electrode plates **146**, and are connected to their respective active capacitor metallizations **164**a and **164**b, thereby are electrically connectable to two leadwires of a hermetic feedthrough for EMI filtering of said leadwires. As such, one leadwire of the hermetic feedthrough is electrically connectable to the active electrode metallization **164**a and a second leadwire of the hermetic feedthrough is electrically connectable to the active electrode metallization **164**b.

FIG. **69**D is the schematic diagram of the X2Y attenuator **210'''** of FIGS. **66** and **69**B. Shown is a line-to-line capacitance Ca-b between lines **142**a and **142**b. Also shown are line-to-ground capacitances Ca and Cb grounded to the ferrule **134**, which are both system grounds. As previously described, by adjusting the size of the active and ground electrode plates or by selectively limiting the number of ground electrode plates, the line-to-line capacitance Ca-b versus the amount of line-to-ground capacitances Ca and Cb can be adjusted.

It is understood that X2Y attenuators come in various sizes and shapes and are not always bipolar devices. X2Y attenuators may have a number of geometries and a number of additional POLES. The X2Y attenuators of the present application are mounted to an EMI filter circuit board for use in an AND for the purpose of illustration; however, can also alternately be used is various other electronic circuitry as well. The X2Y attenuators **210'''** of FIGS. **66** and **69**B are both bipolar X2Y attenuators.

FIG. **70**A illustrates a filter circuit board **130** mounted at, near or adjacent the device side of an AIMD hermetic feedthrough **132** (not labelled). The circuit board **130** of FIG. **70**A is mounted to the device side of the ferrule **134** as shown. The filter circuit board **130** of the present application can be a printed circuit board, an FR4 board, a multi-layer board, an alumina board, a flexible circuit board, or any other type of circuit board known in the art. As previously disclosed for flat-through capacitors **210"**, the circuit board **130** of FIG. **70**A has one or more ground plates **161**, which can be internal ground plates, external ground plates, or a combination of internal and external ground plates. The ground plates are very important in providing low impedance RF decoupling for each of the X2Y attenuators **210"**. A primary difference between X2Y attenuators **210'''** and the flat-through capacitors **210"** previously disclosed is that the circuit current of an AIMD does not pass through the active electrode plates of the flat-through capacitor. The only

currents passing through the active electrode plates of the flat-through capacitor are the decoupled EMI currents.

FIG. 70B is taken from section 70B-70B of FIG. 70A, illustrating a cross-sectional view of the circuit board 130, including the at least one circuit board ground electrode plate 161, which, in this case, is also a shield electrode plate. Ground plates are very important for shielding or covering up at least the bulk of the insulator of a hermetic feedthrough. Emitters in close proximity to a patient having an implanted AIMD, such as cellular telephones, produce strong radiated EMI, which can pass directly through the insulator of a hermetic feedthrough to undesirably couple to sensitive AIMD electronic circuits. Filter circuit boards comprising ground electrode shield plates prevent that direct radiation of EMI energy. In the exemplary embodiment of FIGS. 70A and 70B, the ground electrode plate 161 illustrated, which is also the shield electrode plate, both reflects and absorbs incident radiated energy. In order for the ground electrode plate 161 to effectively reflect and absorb radiated EMI, the ground electrode plate must be connected to the system ground in a very low impedance manner, meaning that both the inductance and the resistance of the electrical connection must be very low. It is appreciated that a multiplicity of ground electrode shield plates 161 can be used in the circuit board 130, including external ground electrode shield plates. Ideally, external ground electrode shield plates are disposed between the surface of the circuit board facing the hermetic feedthrough and the top of the insulator 156 of the hermetic feedthrough, as such a location most effectively reflects and absorbs radiated EMI impinging from the body fluid side of the AIMD.

Referring once again to FIG. 70B, illustrated is a radiated EMI impinging the hermetic feedthrough from the body fluid side of the AIMD. The body fluid side, as illustrated in FIG. 70B, shows both conducted and radiated EMI. Radiated EMI is impinging directly against the insulator 156 of the filtered feedthrough 122 attached to the AIMD housing 124 (not shown). Importantly, the at least one circuit board ground plate 161, which is also a shield electrode plates, reflects and absorbs this radiated EMI. There is also conducted EMI advancing from the body fluid side as illustrated. The conducted EMI is picked up by the implanted leadwires (not shown) and conducted by antenna action along the leadwire of the hermetic feedthrough, which is thereby routed to the device side inside of the AIMD housing. Importantly, the X2Y attenuators 210''' divert the EMI energy from each pair of leadwires to which the X2Y attenuator is connected, for example, to terminal pins 142a and 142b connected to their X2y attenuator respective active capacitor metallizations 164a and 164b, to the common ground of the AIMD, which is the ferrule 134 and the AIMD housing 124 (not shown). In this way, the two different filter capacitors of the X2Y attenuators desirably act as high frequency diverters.

Referring once again to FIG. 70B, illustrated are circuit board rivets 213. Rivets 213 are well known in the art for connecting a ground via hole of the circuit board to the at least one ground plate 161, which in this case is also a shield electrode plate. The rivet 213 can directly contact an oxide-resistant area 248, 250 (not shown) or a gold braze 154c as shown. Alternatively, an electrically conductive material 155 (not shown) may provide electrical connection between said rivet 213 and the oxide-resistant area 248, 250, such as a gold pocket or gold pad, or the gold braze 154c. Oxide-resistant areas including gold pockets, gold pads or equivalent oxide-resistant materials are more thoroughly described in U.S. Pat. No. 10,350,421, the content of which is fully

incorporated herein by this reference. Alternative methods of grounding all types of filter circuit boards will be disclosed later. In all filter circuit board cases, however, it is very important that an oxide-resistant ground connection be made to the ferrule 134 of the hermetic feedthrough of the AIMD.

Ground electrode plates, shield electrode plates, oxide-resistant grounding methods and filter circuit boards are more thoroughly described in U.S. Pat. No. 8,195,295, the content of which is fully incorporated herein by this reference.

Referring back to the flat-through capacitors 210'' and the X2Y attenuators 210'' taught herein, it is noted that these capacitors are of a low k dielectric (k<1,000), the dielectric constant being greater than 0 and less than 1,000. These low k capacitors are the first filter capacitors on the device side inside the AIMD housing, which divert undesirable and/or unwanted EMI to the ferrule and/or the AIMD housing.

FIG. 70C illustrates X2Y attenuators 210''' in a tombstone mounting position, consistent with the embodiments taught herein for the flat-through filter capacitor 210''. For example, the X2Y attenuator 210''' of FIG. 70A can have the active and ground electrode plates disposed perpendicular to the ferrule and insulator device side surfaces of the hermetic feedthrough. The embodiment of FIG. 70C illustrates eight terminal pins 142a through 142h electrically connected respectively to the active capacitor metallizations 164 of the X2Y attenuators 210''' using an electrical connection material 145. Additionally, the circuit board 130 of FIG. 70C is configured to expose the gold braze 154a between the insulator 156 and the ferrule 134 of the hermetic feedthrough. The ground capacitor metallizations 166 of the X2Y attenuators 210'' are directly connected to the gold braze 154a of the hermetic feedthrough using an electrically conductive material 152.

FIG. 70D is an enlarged cross-sectional view taken from section 70D-70D of FIG. 70C. Illustrated are the active electrode plates 144g connected to the left-hand side active capacitor metallization 164, the active electrode plates 144h connected to the right-hand side active capacitor metallization 164h, and the ground electrode plates 146 interleaved with the active electrode plates, which are representative of the electrode plate arrangement of the X2Y attenuators 210''' of FIG. 70C. Additionally, FIG. 70D helps visualizing how the active and ground electrode plates of the X2Y attenuator 210''' are disposed in relation to the ferrule 134 and the insulator 156 of a hermetic feedthrough when the X2Y attenuators are attached in a tombstone mounting position.

It is understood that the X2Y attenuator 210''' can be grounded to the ferrule 134 utilizing any of the methods previously taught herein, including but not limited to, oxide-resistant areas 248, 250, such as gold pockets, gold pads, or other oxide-resistant pockets and pads, peninsulas 139, bridges 141, grounding terminal pins 142gnd, ECA stripes 223, 225 and metal additions 159, 229. Furthermore, the width of the X2Y attenuator 210''' may be increased to accommodate a staggered leadwire hermetic feedthrough design. Wider X2Y attenuators 210''' for staggered leadwire hermetic feedthrough designs may be disposed at an angle to take advantage of the increased distance that exists between the staggered leadwires. It is understood that the X2Y attenuators 210''' can be disposed in the tombstone position on top of circuit board 130, and the circuit board 130 attached to the hermetic feedthrough as illustrated in FIGS. 70A and 70B.

FIG. 71A is taken from FIG. 25 of U.S. provisional 62/646,552 (the '552 provisional), the content of which is

fully incorporated herein by this reference. FIG. 71A illustrates a hermetic feedthrough wherein the ferrule **134** of said hermetic feedthrough comprises oxide-resistant areas **248**, **250**, which are shown as gold pocket-pads.

FIG. **71B** is taken from FIG. 27 of the '552 provisional showing a quad polar rectangular feedthrough filter capacitor **210'** wherein the ground electrode metallization **166** is electrically connected to the oxide-resistant areas **248**, **250** (gold pocket-pads) using an electrically conductive material **152**.

FIG. **71C** is taken from FIG. 31 of the '552 provisional illustrating a feedthrough filter capacitor **210'** attached to a hermetic feedthrough **132**, wherein a filter capacitor width **269** of the feedthrough filter capacitor **210'** is greater than a ferrule width **267** of a ferrule **134** of the hermetic feedthrough **132**. This embodiment is particularly enabling to the present invention as a k<1,000 or mid k filter capacitor (the dielectric material comprising a dielectric constant greater than 0 but less than 1,000) is less volumetrically efficient than the prior art 1,200 k to 2,600 k dielectric filter capacitors, hence is typically bigger than said prior art capacitors. In most AIMDs, such as cardiac pacemakers, ICDs, neurostimulators and the like, there is very little height available for the feedthrough filter capacitor **210'**; however, it is generally possible to increase the filter capacitor width **269** of the feedthrough filter capacitor **210'** if higher capacitance values are needed. Accordingly, a k<1,000 filter capacitor, such as the feedthrough filter capacitor **210'** of FIG. **71C**, which comprises a dielectric constant greater than 0 but less than 1,000 and a filter capacitor width **269** greater than the ferrule width **267** of the ferrule **134** of a hermetic feedthrough **132**, is an enabling distinctive feature of the present invention. Furthermore, oxide-resistant areas **248**, **250**, in accordance with the '552 provisional, provide a unique embodiment for attaching k<1,000 filter capacitors.

Referring once again to FIG. **71C**, it is appreciated that, if higher capacitance is needed, feedthrough filter capacitors **210'** may alternatively comprise a filter capacitor length **273** greater than a length of a ferrule opening **131** (not shown) of a hermetic feedthrough **132**. Given the importance of oxide-resistant attachment as previously explained, that is, so that low inductance and low resistance connections of the ground capacitor metallization **166** of the feedthrough filter capacitor **210'** to the ferrule **134** of the hermetic feedthrough **132** can be made, and considering that a k<1,000 filter capacitor is typically larger in size than prior art filter capacitors in order to match prior art capacitance requirements, oxide-resistant area attachment alternatives provide additional filtered feedthrough design options for meeting application filter requirements. For example, instead of a feedthrough filter capacitor **210'** comprising a short length **273** such that the ground electrode metallization **166** can be attached to the gold braze **154a** that hermetically seals the insulator **156** and the ferrule **134** of the hermetic feedthrough **132**, a feedthrough filter capacitor **210'** can comprise a length **273** greater than a length of a ferrule opening such that the ground electrode metallization **166** can be attached to oxide-resistant areas **248**, **250** disposed on or within the ferrule **134** of the hermetic feedthrough **132**. Attachment of the ground electrode metallization **166** is made using an electrically conductive material **152**. Referring once again to FIG. **71C**, it is understood that the feedthrough filter capacitor **210'** may comprise one of a width **269** greater than the width of the ferrule **134** of the hermetic feedthrough **132** (wherein the feedthrough filter capacitor overhangs at least one edge or a flange of the ferrule), a length **273** greater than the length of a ferrule opening **131** (not shown) of the hermetic feed-

through **132**, or both a width greater than the width of the ferrule and a length longer than the length of the ferrule opening of the hermetic feedthrough, wherein the ground electrode capacitor metallization **166** of the feedthrough filter capacitor **210'** is attached to at least a portion of an oxide-resistant area **248**, **250** using an electrically conductive material **152**. In summary, increasing the width **269** and/or the length **273** of the filter capacitor significantly increases its volumetric efficiency.

Referring once again to FIG. **71C**, one can see that the filter capacitor width **269** is defined by **269e-269e**. Likewise, the filter capacitor length **273** is defined by **273e-273e**. Similarly, the ferrule width **267** is defined by **267e-267e** and the ferrule length **271** is defined by **271e-271e**.

FIG. **72A** is similar to FIG. **71A** except that the gold pocket-pads **248** are now illustrated along the length of the ferrule **134**. In this embodiment, the gold pocket-pads **248** are elongated and shaped to receive a length of an oxide-resistant wire **250** as shown. The oxide-resistant wire **250** may be selected from the group consisting of platinum, gold, tungsten, iridium, palladium, niobium, tantalum, ruthenium, rhodium, silver, osmium, and alloys or combinations thereof. The oxide-resistant material of the ground terminal pins **182**gnd may further be selected from the group consisting of platinum-based materials including platinum-rhodium, platinum-iridium, platinum-palladium, or platinum-gold and naturally occurring alloys such as platiniridium (platinum-iridium), iridiosmium and osmiridium (iridium-osmium). The embodiment of FIG. **72A**, may be designed for attachment of the oxide-resistant wire during a brazing operation such that the oxide-resistant wire is attached at the same time the feedthrough is hermetically sealed. For example, during a single brazing operation, a first gold braze **154a** forms a hermetic seal between the insulator **156** and the ferrule **134**, such as a titanium ferrule; a second gold braze **154b** forms a hermetic seal between each of the terminal pins/leadwires T and **142** and the insulator **156**; and a gold braze wire **250** disposed in the pocket-pads **248** melts and reflows within the pocket-pads **248**. Instead of a gold braze wire **250**, a third gold braze (not shown) disposed within the pocket-pad **248** may alternatively be used to attach an oxide-resistant wire **250** to the ferrule **134**. The use of pocket-pads **248** allows wider and/or longer feedthrough filter capacitors to be attached to a hermetic feedthrough, wherein a ground path can be attached to an oxide-resistant material, and wherein the oxide-resistant material consists of a gold braze material **250** in the form of a gold braze wire or as a gold braze preform to attach an oxide-resistant wire.

It contemplated that a ribbon, a woven wire, a braided mesh, a braided wire, a cable, pressed nano-particles, laminated nano-particles, pressed particles, coils and the like can be used instead of the wire **250**. In addition to gold or pure gold (99.99%), a gold alloy braze material may alternately be used. A preferred gold alloy braze is one which contains more than 50% gold by weight. Non-limiting examples include: 82Au-18In, 88Au-12Ge, the various Johnson Matthey Pallabraze and Orobraze alloys, and the gold alloys of U.S. Pat. No. 4,938,922, the content of which is fully incorporated herein by this reference. Other acceptable metals that form a metallurgical bond to the underlying titanium ferrule, include platinum, palladium or any alloys thereof, including alloys of gold. What is important is that the resulting pocket-pad is oxide-resistant, forms a metallurgical bond with the underlying base metal of the ferrule (which is typically of titanium), and readily accepts an electrical connection. An electrical connection material,

such as a solder, a thermal-setting conductive adhesive or a braze may be used to form the electrical connection.

Referring once again to FIG. 72A, one can see that there are five active terminal pins 142,136 and one telemetry pin marked T. It is appreciated that the telemetry pin T can optionally be hermetically sealed to a separate insulator instead of in a single insulator 156 as shown. Additionally, any of the terminal pins 142,136 can be hermetically sealed into two or more separate insulators 156. Each of the terminal pins 142,136 and the telemetry pin T can be hermetically sealed in individual insulators. It is appreciated that the embodiment of FIG. 72A is not meant to be limiting as any number of active and/or telemetry pins can be hermetically sealed to an insulator of a hermetic feedthrough. Additionally, it is not necessary that the terminal pins be in-line as shown in FIG. 27 but can be hermetically in the insulator in any position required by an application. For example, the terminal pins of a feedthrough can alternatively be hermetically sealed in one of a staggered terminal pin configuration, a dual in-line terminal pin configuration, diagonally spaced in pairs, or a custom terminal pin configuration.

Referring once again to FIG. 72A, the elongated pocket-pads 248 are generally very shallow and may be separately machined after the ferrule is made, or may alternatively be formed during the machining, stamping or metal injection molding of the ferrule 134. One convenient way to manufacture the elongated pocket-pads 248 is with a ball-shaped cutting tool of an end mill that only partially penetrates the surface of the ferrule. The pocket-pads 248 are generally very narrow, for example, 1 mil to 4 mils, allowing a small diameter oxide-resistant wire 250, for example, less than 1 mil to 2 mils, to be used. As previously disclosed, oxides of titanium are generally only angstroms thick. Therefore, even a 1 mil coating of an oxide-resistant material is sufficient to prevent titanium oxidation thereby providing an oxide-resistant attachment surface.

Referring now back to FIG. 71A, it is understood that the gold pocket-pads 248 of FIG. 71A can be elongated similar to the elongated pocket-pads of FIG. 72A such that a thin gold wire can be used, thereby providing a single elongated oxide-resistant attachment surface along the width at both ends of the ferrule 134. Referring again to FIG. 71A, it is also understood that the gold pocket-pads 248 can be made at the corners of the ferrule 134 to facilitate suitable electrical connection should it be needed. Regardless of the oxide-resistant pocket-pad location or configuration, the pocket-pad 248 design should be made so that an oxide-resistant electrical connection can be made to the ground capacitor metallization 166 of the filter capacitor, whether that ground capacitor metallization 166 resides on the short side, the long side, or both the short and the long sides of said filter capacitor.

FIG. 72B illustrates a filter capacitor 210' mounted atop the hermetic feedthrough of FIG. 72A forming a filtered feedthrough 122. Importantly, the telemetry pin T of the hermetic feedthrough is not included in the filter capacitor 210' because the telemetry signal is a high frequency signal that is filtered by the filter capacitor 210'. In general, high frequency filtering by a feedthrough filter capacitor 210' cannot be applied to telemetry pins, as the telemetry signal, being a high frequency signal, is attenuated rendering the telemetry pin ineffective. All of the active terminal pins 142, however, passing through and electrically connected to the filter capacitor 210' are appropriately filtered. Importantly, the ground capacitor metallization (termination) 166, which contacts the filter capacitor's ground electrode plates 146,

are electrically attached using an electrically conductive material 152 such as a solder or a thermal-setting conductive adhesive. It is noted that the electrically conductive material 152 of FIG. 72B is shown electrically connecting across the full length of the oxide-resistant pocket-pad 248, 250, however, the electrically conductive material 152 may alternatively at least partially contact the gold braze or wire 250 associated with pocket-pad 248.

Referring once again to FIG. 72B, it is not necessary that the oxide-resistant pocket-pad 248, 250 extend the whole length of a feedthrough filter capacitor. It can extend, for example, for three quarters of the length and be centered and will work just fine from an electrical high-frequency impedance point of view. The oxide-resistant pocket-pad 248, 250 can also be discontinuous, for example, two or three short oxide-resistant pocket-pad segments distributed along the length on each side of the ferrule 134 are sufficient in the event that the cost of the oxide-resistant material, such as a gold, is a concern. Since the oxide-resistant pocket-pad 248 of the present application is like a swimming pool-type structure, small amounts of gold such as very thin ribbons or foils, or even small diameter wires, can be used. This swimming-pool structure approach is totally unlike anything in the prior art, as gold, for example, a gold braze, is always free to flow and used in large quantities to be effective. Accordingly, the filter capacitor of FIG. 72B provides excellent attenuation at all frequencies up to 3 GHz, or even 10 GHz and beyond, thereby, attenuating undesirable interferences from, for example, cellular telephones, microwave ovens and the like.

The attachment to an oxide-resistant metallurgically bonded surface 248, 250, such as a gold braze or a gold pocket-pad, is very important to properly ground the feedthrough filter capacitor 210'. In the prior art, the inventors know of one attempt to eliminate an attachment to gold and instead clean the titanium surface of the titanium ferrule 134 so that a stripe of a thermal-setting electrically conductive adhesive can be painted on the surface of the titanium (the painted thermal-setting electrically conductive adhesive stripe is typically known as an ECA stripe). The problem with an ECA stripe painted directly on the surface of a cleaned titanium is that a titanium metal easily re-oxidizes. In fact, a surface titanium oxide film forms almost instantly when a fresh titanium metal surface is exposed to air and/or moisture. Even a damaged titanium oxide film can generally re-heal itself instantaneously if even at least traces (that is, a few parts per million) of oxygen or water are present in an environment. Researchers have proven that within a millisecond of exposure to air, a 10 nm oxide layer will be formed on a cut surface of exposed essentially pure titanium metal, which will grow to about 100 nm thick within a minute. Hence, a first problem of an ECA stripe directly applied to a cleaned titanium surface results from the ECA stripe typically being cured at a high-temperature, between 200° C. and 300° C., in air. Thus, during curing in air, a titanium oxide re-forms on the surface of a cleaned titanium between the ECA stripe and the bulk titanium of the ferrule. A second problem of an ECA stripe is due to an oxygen release from the ECA during curing in addition to the air environment thereof. It is known that elevated temperature exposure of an ECA, such as an epoxy or a polymer, allows release or outgassing of oxygen and/or oxygen-containing constituents or residues that may be present within the ECA material. Hence, this added exposure to released oxygen or oxygen-containing constituents from the ECA stripe further causes a thickening of the oxide layer resultant from curing the ECA stripe in air. A third problem regarding ECA stripes is that

the filtered feedthrough **122** of FIG. **72B** is designed to be laser welded into an opening of an active implantable medical device housing, for example, an opening in the housing of a cardiac pacemaker. Laser welding imparts a very high temperature rise to occur in the area of the ECA stripe connecting the feedthrough filter capacitor **210'** to the titanium ferrule of a hermetic feedthrough **132** (not labelled). Heating of an epoxy or a polymer during laser welding is sufficient to raise the temperature at, near or adjacent the laser weld such that a further release of oxygen or oxygen-containing constituents or residues, including any moisture (H_2O) associated with said epoxy or polymer, further contributes to oxidizing the titanium metal between the ECA stripe and the surface of the ferrule **134**. As such, titanium oxides can be removed mechanically or chemically from a titanium ferrule by either abrasive grit blasting, such as by alumina blasting, mechanical grinding, sanding processes, hydrofluoric acid cleaning, or combinations thereof; however, the titanium oxides typically re-form due to titanium being a highly reactive material that has an extremely high affinity for oxygen. While a titanium oxide layer on the highly reactive titanium metal surface imparts good corrosion behavior and high biocompatibility, the titanium oxide layer can and does negatively impact AIMD EMI filter performance, the negative impact being particularly observable at higher frequency applications. When titanium oxides develop between an ECA stripe and the cleaned titanium surface of the ferrule of a hermetic feedthrough, the equivalent series resistance (ESR)/insertion loss (IL) of the EMI filter can dangerously increase due to the very presence of the titanium oxides such that EMI filtering is compromised. Such ESR/IL increases are particularly observable at frequencies above 10 MHz. Of particular significance, is that such ESR/IL increases (in other words, EMI capacitor ohmic losses) are often masked at low frequencies by an EMI filter's dielectric losses. Such masking is particularly egregious to present day pacemakers and implantable cardioverter-defibrillators, which are considered/labelled MRI conditionally approved, as in an MRI environment, EMI filters divert substantial, potentially dangerous, RF current generated in implanted therapy delivery leads of an AIMD during MRI to the AIMD housing for dissipation. Hence, reliance solely on ECA stripe direct attachment to an oxidizable metal surface, such as a titanium surface, is considered to be dangerous and of poor practice by the inventors. It is also important to note that titanium oxides can also compromise performance in switching applications, coupling applications, and bypass applications in addition to EMI filtering applications.

In summary, the oxide-resistant pocket-pads **248**, **248'**, **250**, **250'** of the present invention prevent re-oxidation of a cleaned titanium surface, as such oxide-resistant pocket-pads provide a metallurgical bond to the base metal of the ferrule that affords a reliable, long-term, stable, and low impedance electrical connection to the ground capacitor metallization **166** of the feedthrough filter capacitor **210'**. A reliable, long-term, stable, and low impedance electrical connection to the ground capacitor metallization **166** of the feedthrough filter capacitor **210'** to the hermetic feedthrough **132** is particularly important for modern pacemakers and defibrillators, which are now generally labelled MRI conditionally approved. As previously disclosed, in an MRI environment, the feedthrough capacitor **210'** diverts a very large amount of RF current that is picked up by the implanted leads during an MRI scan to the housing of the AIMD. Accordingly, a great deal of RF current passes directly through the ground capacitor metallization **166**,

through the electrical attachment material **152**, to the oxide-resistant gold pocket-pad **248**, **250**, and, in turn, to the ferrule **134** for dissipation by the AIMD housing to which the ferrule is laser welded. Thus, the conductive housing of the AIMD acts as an overall energy dissipating surface for this diverted MRI energy, and, as previously stated, relying solely on a thermal-setting conductive adhesive attachment to an oxidizable surface like titanium, is considered to poor practice and dangerous.

FIG. **72C** is similar to FIG. **72B** except that the ground capacitor metallization (termination) **166** is along two short ends of the filter capacitor **210'** and electrical attachment is made to a gold braze **154a** of the heretic feedthrough **132** (not labelled). The electrical attachment to a gold braze is disclosed in U.S. Pat. No. 6,765,779, the content of which is fully incorporated herein by this reference. In accordance with the present invention, the feedthrough filter capacitor **210'** extends beyond the edges of the width of (in other words, overhangs) the ferrule as shown, thereby increasing the capacitors effective capacitance area or ECA. This is particularly important for enabling filter capacitors that have a dielectric constant less than 1,000 k or even less than 500 k as larger electrode plates can be made. Alternatively, the feedthrough filter capacitor **210'** may only extend to the edges of the width of the ferrule. Another alternative embodiment is that one side of the feedthrough filter capacitor **210'** may extend to an edge of the width of the ferrule while the opposite side of the feedthrough filter capacitor **210'** overhangs the edge of the width of the ferrule.

FIG. **73** is a cross-section taken generally from section **73-73** of FIG. **72B** illustrating a feedthrough filter capacitor **210'**, including its internal electrode plates. The ground electrode plates are labelled **146** and the active electrode plates are labelled **144**. Importantly, the capacitor's ground electrode plates **146** are attached to a ground capacitor metallization (termination) **166** using an electrically conductive material **152**, which at least partially connects to an oxide-resistant pocket-pad **248** (not labelled) such as gold braze or a gold pocket-pad **250**.

Referring once again to FIG. **73**, it is noted that a dramatic improvement in volumetric efficiency of the filter capacitor **210'** is achieved because the filter capacitor is much wider in size, therefore, the overlap of the interleaved electrode plates **144** and **146** is also much greater. The larger sized electrode plates due to the increased filter capacitor width thereby increases the capacitor's "effective capacitance area" (ECA). Increased ECA, s previously disclosed, is particularly enabling for a filter capacitor having dielectric constant k less than 1,000 or 500. By increasing the ECA of low k filter capacitors, one can achieve the required capacitance value needed to effectively filter EMI without sacrificing EMI filter reliability. In this embodiment, because the filter capacitor **210'** is wider, the ground capacitor metallizations **166** are electrically connected to the oxide-resistant pocket-pads **250**, which can be gold or gold braze pocket-pads. The oxide-resistant pocket-pads **250** enable attachment of a wider filter capacitor **250'** to the hermetic feedthrough **132** such that both an increased ECA and an oxide-resistant electrical attachment to the ferrule **134** is achieved. Looking closely at the left-hand side of the ferrule **134** of the hermetic feedthrough **132**, one can see that the oxide-resistant pocket-pad **250** is rounded and on the right-hand side of the ferrule **134** of the hermetic feedthrough **132**, the oxide-resistant pocket-pad **250** has square corners. As previously disclosed, the oxide-resistant pocket-pads **250** can be made by machining, stamping or metal injection molding the ferrule **134**. For example, if machining is used, the rounded shape can easily

be machined with a ball mill end. Additionally, either a rounded, a rectangular or a square shaped oxide-resistant pocket-pad **250** can alternatively be achieved by stamping and metal injection molding. Also, as previously disclosed, the feedthrough filter capacitor **210'** may only extend to the edges of the width of the ferrule, or one side of the feedthrough filter capacitor **210'** may extend to an edge of the width of the ferrule while the opposite side of the feedthrough filter capacitor **210'** may overhang the edge of the width of the ferrule. In an embodiment, the filter capacitor **210'** is electrically connected to both an oxide-resistant pocket-pad **250** of the ferrule **134** of the filtered feedthrough **132** and at least a portion of the gold braze **154a** hermetically sealing the insulator **156** and the ferrule **134** of the hermetic feedthrough **132**.

Referring once again to FIG. **73**, one can see that the terminal pin **142,136** is continuous from the device side (**142**) to the body fluid side (**136**). The terminal pin **142,136** is gold brazed **154b** to the insulator **156** such that a hermetic seal is formed. The insulator comprises via hole metallizations (not labelled) that are sputtered on the insulator **156** as shown. It is understood that one or more sputter layers are applied to the insulator via holes to facilitate wetting of a braze material. In some embodiments, a first sputter layer is applied to the insulator via hole, which is an adhesion layer, and a second layer is applied over the adhesion layer, which is a wetting layer. In some embodiments, a single layer which has both adhesion and wetting properties is applied to an insulator via hole. Importantly, electrically conductive material **168** flows down through the passageway of the feedthrough capacitor (also known as a feedthrough capacitor via hole) and contacts the active capacitor metallization **164** of the capacitor via hole and the gold braze **154b** of the hermetic feedthrough **132**. Accordingly, an oxide-resistant electrical connection is made between the active capacitor metallization **164** and the gold braze **154b** of the hermetic feedthrough **132** using an electrically conductive material **168**. An oxide-resistant electrical connection is very important if the terminal pin **142**. **136** comprises an oxidizable material, for example, niobium, tantalum, titanium or molybdenum. The oxide-resistant electrical connection is also particularly important if the terminal pins comprise alloys, such as platinum-iridium or palladium-iridium alloys, as even a small percentage of iridium can cause oxidation on the surface of the terminal pin. During the brazing process, the gold braze **154b** burns through a terminal pin oxide layer thereby forming a low resistance, low impedance metallurgical bond to the base metal of said terminal pin. Attaching the active capacitor metallization of a capacitor via hole to the gold braze of a terminal pin of a hermetic feedthrough is more thoroughly disclosed in U.S. Pat. No. 6,888,715, the content of which is fully incorporated herein by this reference.

FIGS. **74A**, **74B** and **74C** are taken from FIGS. 32A, 32B and 32C of U.S. Provisional application, Ser. No. 62/646, 552 (the '552 provisional). These figures illustrate an internally grounded feedthrough filter capacitor **210'i** that has no diameter or perimeter metallization at all. In other words, the electrode ground plates of the filter capacitor **210'i** are grounded through a ground terminal pin **142gnd**. Referring to FIG. **74C**, it is appreciated that, since there is no need for any external ground capacitor metallization for electrical connection between the feedthrough capacitor and the ferrule, the need for the gold pocket-pads of the ferrule is also completely eliminated. However, importantly, it is also appreciated that, for a low k filter capacitor k<1,000, to substantially increase the ECA of the filter capacitor, said

filter capacitor of FIG. **74C** can be designed to significantly overhang the ferrule in either the width, the length or both the width and length dimensions. Accordingly, internally grounded feedthrough filter capacitors in combination with low k dielectric filter capacitors k<1,000 can be designed to fit very tight geometries characteristic inside the hermetically sealed housing of modern AIMDs.

FIG. **75** is taken from FIG. 37 of the '552 provisional. In this embodiment, illustrated is a long rectangular feedthrough filter capacitor **210'h**, which comprises and internal ground terminal pin **142gnd** and external end ground capacitor metallizations **166**. This embodiment is a hybrid filter capacitor, as the filter capacitor **210'h** comprises both internal and external grounding technologies. Hybrid filter capacitors are best understood by referring to the cross-sectional view shown in FIG. **76** taken from FIG. 38 of the '552 provisional.

Referring back to FIG. **75**, it is understood that other shapes can be used for this filter capacitor embodiment such as previously disclosed, meaning that the filter capacitor of FIG. **75** can be flush with the edge of the ferrule of the hermetic feedthrough, or alternatively overhang one or more edges of the ferrule of the hermetic feedthrough. For example, the rectangular-shaped capacitor can have rounded corners. Alternatively, the capacitor can even be round, oblong (racetrack) or any other geometric shape possible, where a portion of the capacitor is either flush with or overhangs the edges of the ferrule to greatly increase the ECA of the filter capacitor. It is understood that oxide-resistant attachments can also similarly be made.

FIG. **76** is taken from cross-section **76-76** of FIG. **75** showing the internal construction of the hybrid feedthrough filter capacitor **210'h**. Illustrated in more detail are the ground electrode plates **146** and active electrode plates **144** of the hybrid filter capacitor. In the center of the hybrid filter capacitor, one can see a ground terminal pin **142gnd**, which is gold brazed **154b'** to either a peninsula **139** or a bridge **141** embodied by the ferrule **134**. Importantly, ground terminal pin **142gnd** is attached in a very low resistance and low impedance manner so that the hybrid filter capacitor can divert high frequency RF energy through the ground terminal pin **182gnd** to the ferrule **134** and then, in turn, to the AIMD housing (not shown). It is appreciated that all the ferrule embodiments disclosed herein are configured to be laser welded into an opening of the housing of an AIMD; however, it is understood that the ferrule may be co-formed with the housing of the AIMD, or a ferrule may be entirely omitted, with the insulator of the hermetic feedthrough being directly hermetically sealed to the AIMD housing itself.

Referring once again to FIG. **76**, one can see that the ground electrode plates **146** are electrically connected to the internal ground terminal pin **142gnd** and to the external metallizations **166** on opposite ends of the rectangular hybrid filter capacitor as shown. These ground capacitor metallizations **166** are electrically connected to the novel oxide-resistant pocket-pads **250** using an electrically conductive material **152**. Hence, the term "hybrid" internally grounded filter capacitor **210'h**, as the ground electrode plates are grounded both to the ground terminal pin **142gnd** and to the external ground capacitor metallizations **166**. Hybrid filter capacitor electrical connections are particularly enabling when the filter capacitor becomes long, and the active terminal pins are a substantial distance (a long way or distant) from the ground terminal pin **142gnd**, as the inductance and the resistance can build up across the ground electrode plates such that the insertion loss or filter perfor-

mance of the terminal pins furthest away from the ground terminal pins **142**gnd is degraded. Referring once again to FIG. **76**, it is also appreciated that additional ground terminal pins **142**gnd can be added as necessary for optimal filter performance. In accordance with the present invention, one can see that the filter capacitor of FIG. **76** has a high number of internal electrode plates, which is essential to drive down its equivalent series resistance (ESR).

FIG. **77** is taken from FIG. **41** of the '552 provisional, which illustrates that instead of ground terminal pins, the insulator has co-sintered paste-filled vias. In this embodiment, the co-sintered paste-filled vias comprise a ceramic reinforced metal composite (CRMC) **185** having essentially pure platinum end caps **187**. Referring back to FIG. **77**, it is appreciated that the co-sintered paste-filled via can alternatively be entirely replaced by a substantially pure platinum (Pt), as described in U.S. Pat. Nos. 8,653,384 and 9,492,659, the contents of which are fully incorporated herein by these references. The CRMC **185** may also comprise a CERMET. Additionally, the co-sintered paste-filled vias of the present application may further comprise any of the CRMC/Pt paste-filled via embodiments disclosed in the '552 provisional. Novel oxide-resistant pocket-pads **250** and **250'** are provided for grounding the internally grounded feedthrough filter capacitor **210'**i of FIG. **77**. In this embodiment, the feedthrough filter capacitor also has solid-filled vias **119'**, **119"**, **199**gnd, and an electrical connection material **203**, which can be a BGA, microdots or solder bumps. The electrical connection material further comprises one of a solder, a thermal-setting conductive adhesive, a thermal-setting conductive epoxy or combinations thereof. As such, the feedthrough filter capacitor **210'**i can be electrically connected to both the grounding oxide-resistant pocket-pads **250**, for example a gold pocket-pad, and also to the active co-sintered paste-filled vias in one operation. Referring once again to FIG. **77**, it is appreciated that because of the presence of the oxide-resistant pocket-pads, the filter capacitor can be made substantially wider than the width of the ferrule, thereby keeping the height of the filter capacitor relatively low while increasing the volumetric efficiency of the filter capacitor for use in an AIMD. Referring again to FIG. **77**, because the internally grounded feedthrough capacitor does not have any external capacitor metallization and therefore no external electrical connection material for attaching to the ferrule, the filter capacitor is mechanically free to float during laser welding of the hermetic feedthrough **132** into an opening of the AIMD housing **124**. The laser weld is labelled **157**. Since the laser welding can cause a great deal of heat and thermal stress, it is advantageous for the internally grounded feedthrough filter capacitor **210'**i to be free floating during such laser welding. Experiments by the inventors have shown that the absence of electrical connection material mitigated thermal coefficient of expansion mismatch of the filtered feedthrough, and in particular, of the filter capacitor **210'**i itself, due to heat imparted during laser welding. Moreover, because there is no electrical connection material required, the feedthrough filter capacitor can not only extend to the edges of the length and the width of the ferrule, but also can overhang the edges of both the length and the width of the ferrule, thereby providing increased ECA.

FIG. **78** is taken from FIG. **41B** of the '552 provisional. FIG. **78** is similar to FIG. **77**, except that all of the electrical connections are by way of an anisotropic conductive film (ACF). The novel nail-head **261** of the leadwires shown are pre-assembled to the feedthrough filter capacitor and stand proud of said feedthrough filter capacitor, thereby, providing

a mating surface in which the conductive particles within the ACF can be compressed to form an electrical connection between the nail-heads of the leadwires and the platinum cap of the co-sintered past-filled vias as shown. Referring again to FIG. **78**, it is appreciated that, while the feedthrough filter capacitor in this embodiment is shown having the same width as the width of the ferrule, the filter capacitor can alternatively overhang the width of the ferrule. Again, this is particularly important for filter capacitors having low k dielectric constants k<1,000.

FIG. **79** is taken from FIG. **48** of the '552 provisional illustrating a filter circuit board **130** disposed on one of the ferrule **134**, the insulator **156**, or both the ferrule and the insulator of the hermetic feedthrough **132**. The filter circuit board **130** may alternatively be disposed adjacent on one of the ferrule **134**, the insulator **156**, or both the ferrule and the insulator of the hermetic feedthrough **132**. Illustrated are various exemplary embodiments of co-sinter paste-filled via conductive pathways extending to the device and the body fluid sides of the insulator **156** of the hermetic feedthrough **132** (not labelled). It is understood that the co-sintered paste-filled via conductive pathways may have numerous combinations of CRMC, CERMETS, pure platinum, solid wires, terminal pins, leadwires, two-part pins, metal inserts and the like to form various conductive pathway configurations. One is referred to the '552 provisional for additional detail regarding co-sinter paste-filled via conductive pathways. Importantly, the filter circuit board **130** and its associated leadwires **142** are each electrically connected to a corresponding conductive pathway of the insulator as illustrated. In this exemplary embodiment, the filter circuit board **130** has at least one internal ground electrode plate **161**. A low impedance and low resistance electrical connection is made from the internal ground electrode plate **161** of the filter circuit board **130** through the circuit board ground vias through an electrical connection material **203** to oxide-resistant pocket-pads **250** to the ferrule **134** as illustrated. It is appreciated that 2, 3 or "n" number of ground electrode plates **161** can be disposed on the surface of the filter circuit board **130** or embedded within the body of the filter circuit board **130** or both disposed on the surface of the circuit board and embedded within the body of the circuit board. In an embodiment, there are at least two internal ground electrode plates and at least one external ground electrode plate, the at least one external ground electrode plate being disposed between the filter circuit board and the device side of the insulator and/or the ferrule of the hermetic feedthrough.

Also illustrated in FIG. **79** are filter capacitors electrically connected to the active terminal pins (there are 6 shown in this example embodiment) and to the ground via holes of the filter circuit board **130**. The filter circuit board illustrated has one filter circuit board ground electrode plate **161**. It is noted that the filter circuit board **130** of the present application comprises at least one filter circuit board ground electrode plate. The at least one filter circuit board ground electrode plate may be either an external ground electrode plate (meaning that the ground electrode plate is disposed on the filter circuit board) or an internal ground electrode plate (meaning that the ground electrode plate is embedded within the body of the circuit board). Each filter capacitor of the filter circuit board is configured to divert high frequency energy from the active terminal pins **142**a through **14**f to the ferrule **134** of the hermetic feedthrough **132** (not labelled) to the AIMD housing (not shown), the ferrule and housing being the AIMD ground. The filter capacitors of the present application are selected from the group consisting of an

MLCC chip capacitor **210**, an X2Y attenuator **210"**, a flat-through capacitor **210"**, or combinations thereof.

Referring back to FIG. **79**, it is understood by those skilled in the art that a wire **187**W of a conductive pathway of the hermetic feedthrough can be extended beyond the thickness of the insulator **156** of the hermetic feedthrough to the body fluid side, to the device side, or both to the body fluid and device sides of said hermetic feedthrough for attachment to either internal circuits of the AIMD or to the connectors or other electronic components of the header block. Furthermore, the CRMC **185** or the CRMC **185** and the Pt **187** materials of the co-sintered paste-filled vias illustrated may be replaced entirely by only an essentially pure platinum co-sintered paste-filled via as disclosed by the incorporated U.S. Pat. Nos. 8,653,384 and 9,492,659. The far-right co-sintered paste-filled via is exemplary of an essentially pure platinum **187** co-sintered conductive pathway of a hermetic feedthrough.

FIG. **80** is taken from FIG. 129 of U.S. Pat. No. 10,272, 253, referred to hereinafter as the 253 patent, the content of which is fully incorporated herein by this reference. FIG. **80** illustrates a general top view of an exemplary embodiment of the filter circuit board **130** of FIG. **79**. In this exemplary embodiment, the MLCC chip capacitors **210** are electrically connected to the active terminal pins **142***a* through **142***f* and to the ground via holes **163***a* through **163***f* using circuit traces disposed on the filter circuit board **130**.

FIG. **81**, which is taken from FIG. 130 of the '253 patent, is a sectional view of **81-81** of FIG. **80**. Illustrated is a ground electrode plate **161** electrically connected to each of the ground via holes of the filter circuit board **130** (not labelled). Accordingly, each one of the MLCC chip capacitors **210** of filter circuit board of FIG. **80** is physically disposed very close to their corresponding ground via hole **163***a* through **163***f* and is electrically connected in a low resistance and low impedance manner through the ground via holes **163***a* through **163***f* of the filter circuit board to the co-sintered paste-filled via active conductive pathways of the hermetic feedthrough forming the filtered feedthrough **122** as shown. Referring back to FIG. **80**, the circuit traces of the filter circuit board have active circuit traces **205** and ground circuit traces **207**. It is contemplated that the MLCC chip capacitor can be positioned on the filter circuit board such that the length of the active circuit trace **205** can be shortened while the ground circuit trace **207** can be lengthened. It is also contemplated that by simply moving or realigning the MLCC chip capacitor, the ground circuit trace **207** can be completely eliminated. By moving or realigning the MLCC chip capacitor, the ground termination **166** of each MLCC chip capacitor **210** can butt up and directly be attached to their corresponding ground via hole **163***a* through **163***f* making the ground electrical connection. It is also contemplated that by rotating and lengthening the MLCC chip capacitor, the active circuit trace **205** can also be eliminated. By rotating and lengthening the MLCC chip capacitor **210**, the active termination **164** of the MLCC chip capacitor can butt up and directly be attached to their corresponding active terminal pins **142***a* through **142***f* making the active electrical connection. As such, re-positioning and/or changing the size of the MLCC chip capacitor and/or adjusting the length of or eliminating either the active circuit trace **205** or the ground circuit trace **207** or both the active circuit trace **205** and the ground circuit trace **207** allows circuit board design flexibility, which can be important, for example, when size limitations or enhanced filter performance are required.

FIG. **82**, which is taken from FIG. 131 of the '253 patent, is a sectional view of **82-82** of FIG. **80**. Illustrated is a filtered feedthrough **122** having ground terminal pins attached to the ferrule **134** of a hermetic feedthrough (not labelled). On the left-hand side of FIG. **82**, a ground terminal pin **142**gnd is brazed into a via hole that extends through the thickness of the ferrule **134**. On the right-hand side of FIG. **82**, a ground terminal pin **142'**gnd is attached within a counterbore of the ferrule **134**. It is contemplated that more than two or "n" number of ground terminal pins may be brazed into a ferrule **134** of a hermetic feedthrough **132**. Further, it is contemplated the hermetic feedthrough may have ground terminal pin embodiments that are the same or different pending the requirement of the application. The embodiments of FIG. **82** are not limiting. It is contemplated that the ground terminal pins may alternatively be attached to a peninsula or a bridge of a ferrule, to pocket-pads residing on or in a ferrule, or combinations thereof, so that a ground electrical connection can be made to the filter circuit board of a filtered feedthrough. While FIG. **82** shows ground terminal pins attached to the ferrule, it is understood that the ground terminal pins may be replaced with filled ground vias. Additionally, a filtered feedthrough may comprise a ferrule having any number and or combination of ground terminal pins and ground filled vias for grounding.

FIG. **83** taken from FIG. 132 of the '253 patent is a sectional view of **83-83** of FIG. **80** illustrating the ground electrical connections **163***b*, **163***d* and **163***f* to respective MLCC chip capacitors **210**.

FIG. **84** is similar to FIG. 159 of the '253 patent except that FIG. **84** has an active terminal pin passing all the way through the conductive pathway of the insulator **156** of the hermetic feedthrough. It is noted that the active terminal pin is labelled **142** on the device side and **136** on the body fluid side. The terminal pin is shown gold brazed **154***b* to sputtered metalized surfaces of the alumina insulator **156**, thereby hermetically sealing the terminal pin **142**,**136** and the insulator **156**. Referring once again to FIG. **84**, one can see that there is a gold meniscus **154***b*' that forms at the terminal pin **142** during the high temperature gold brazing operation. The gold meniscus **154***b*' provides an electrical connection **145** between the filter capacitor **210** active capacitor metallization **164** and the gold braze meniscus **154***b*' as shown. The gold braze electrical connection **145** enabled by the gold braze meniscus **154***b*' is important because attaching to an oxide-resistant material, such as the gold braze meniscus **154***b*', makes a low resistant and low impedance electrical connection between the capacitor active termination **164** and the feedthrough pin **142**. Moreover, such oxide-resistant electrical connections enable the use of highly oxidizable terminal pins **142**,**136**, for example, niobium, tantalum, molybdenum or the like.

FIG. **78** is taken from FIG. 41B of the '552 provisional. FIG. **78** is similar to FIG. **77**, except that all of the electrical connections are by way of an anisotropic conductive film (ACF) **213'**. The novel nail-head **261** of the leadwires shown are pre-assembled to the feedthrough filter capacitor and stand proud of said feedthrough filter capacitor, thereby, providing a mating surface in which the conductive particles within the ACF can be compressed to form an electrical connection between the nail-heads of the leadwires and the platinum cap of the co-sintered past-filled vias as shown. Referring again to FIG. **78**, it is appreciated that, while the feedthrough filter capacitor in this embodiment is shown having the same width as the width of the ferrule, the filter capacitor can alternatively overhang the width of the ferrule.

Again, this is particularly important for filter capacitors having low k dielectric constants k<1,000.

FIG. **85** is taken from FIG. 23 of U.S. Pat. No. 10,272, 252, hereinafter referred to as '252 patent, the content of which is fully incorporated herein by this reference. It is contemplated that the present invention applies to any of the embodiments disclosed in the '252 patent. Referring to FIG. **85**, illustrated is a novel two-part pin residing within a conductive pathway of a filtered feedthrough **122** (not labelled). Because the conductive pathway of the hermetic feedthrough comprises a two-part pin, the body fluid side of the hermetic feedthrough can comprise a first terminal pin **136** that is low cost but biocompatible, such as niobium, tantalum, titanium, molybdenum or the like. The second pin **117** of the two-part pin can then be an oxide-resistant terminal pin, for example, platinum, palladium or alloys thereof, so that a low resistance and low impedance electrical connection can be made when the filter capacitor is attached to the hermetic feedthrough, thereby forming a filtered feedthrough. As illustrated in FIG. **85**, a gold braze **154**b co-joins and co-brazes the body fluid side terminal pin **136** to the device side terminal pin **117**. In an embodiment (shown on the right side of FIG. **85**), the two-part pin may be joined, for example by welding **424**, before co-brazing. The device side terminal pin **117** is shown as a short pin to which a third pin is provided within the capacitor conductive pathway of a feedthrough filter capacitor **210'**. The third pin is attached to the two-part of the hermetic feedthrough using an electrically conductive material **168** as illustrated. In this embodiment, therefore, the third pin can be low cost pin **142** or leadwire, such as copper, aluminum, copper-beryllium, tin-copper, that can then be routed to the device electronic circuits (such as the device circuit board not shown). Alternatively, the device side terminal pin **117** of the hermetic feedthrough may optionally extend all the way through the conductive pathway of the feedthrough filter capacitor **210'** for attachment to the AIMD electronics, thereby eliminating the third pin. The feedthrough filter capacitor **210'** of FIG. **85** is a conventional filter capacitor having an external or perimeter ground capacitor metallization. Shown is a ground electrical connection between the external or perimeter ground capacitor metallization of the filter capacitor **210'** and the gold braze **154**a hermetically sealing the ferrule **134** to the insulator **156** of the hermetic feedthrough using an electrically conductive material **152**. The electrically conductive material **152** contacts at least a portion of the gold braze **154**a. As previously disclosed, electrical connection may alternatively be to a gold pocket-pad. It is appreciated that the feedthrough filter capacitor **210'** can alternatively be an internally grounded filter capacitor **210'**i, thereby eliminating the need for an external ground electrical connection.

FIG. **85** also shows an insulator metallization **177**, **179** at least partially disposed on the perimeter surface of the insulator **156**. A first gold braze **154**a hermetically seals the ferrule **134** to the insulator metallization. The insulator metallization may comprise an adhesion layer **177** and a wetting layer **179**, wherein the adhesion layer is disposed on the insulator and the wetting layer is disposed on the adhesion layer; however, the insulator metallization may comprise one layer having both adhesion and wetting properties. The insulator metallization may further comprise a titanium adhesion layer and a molybdenum and/or a niobium wetting layer.

FIG. **86** is a flow chart taken from FIG. 165 of U.S. Pat. No. 10,249,415, the content of which is fully incorporated herein by this reference. A pressing (also known as a second lamination step or second pressing step) is shown between

the "Fill with Pt paste" and "Singulate" method steps. The inventors have discovered that this second pressing step is very important as the second pressing step forces the conductive via filled pastes into every opening, nook and cranny along their interfaces, facilitating co-sintering. This second pressing step is also important as the intimacy provided between the ceramic insulator and the conductive paste permits diffusion and bonding of the ceramic and the conductive paste along their interface, which is disclosed in more detail below.

Referring once again to FIG. **86**, during the "Fill with CRMC" step, at least some small air cavities or vacancies are created. The "Dry" step prepares the insulator paste-filled vias for drilling so that a platinum paste can be added, which may create yet more air pockets or voids. The addition of a second pressing step, wherein an entire green bar or insulator body is pressed under very high pressure, by either mechanical or isostatic pressing, forcing compaction and flow of the CRMC **185** and/or the platinum **187** pastes to fill and close such voids, thereby forming a more solid void-free or air pocket-free green bar or insulator. The laminated green bar of insulator body can then be singulated and fired.

FIG. **87** is a cross-sectional perspective of a laminate embodiment that illustrates stacked laminated sheets prior to the second "Pressing" step in accordance with the left-hand side of the flow chart FIG. **86**. The dashed lamination lines **216** indicate the layers of stacked sheets. It is understood that the insulator may comprise a single solid green body (see the right-hand side of the flow chart of FIG. **86**), thus the dashed lamination lines **216** of FIG. **87** would not be present.

FIG. **87** is idealized, in that, it shows an alumina substrate **156** that has a drilled via hole that is completely filled with a paste comprising CRMC **185**, is then dried, drilled and re-filled again with a paste comprising pure platinum or substantially pure platinum **187**. At very high magnification levels, one would see air bubble, voids or open pockets along the interface between the CRMC **185** and the alumina **156** and between the platinum **187** and the CRMC **185** pastes.

FIG. **88** shows what happens to FIG. **87** after the addition of the novel second "Pressing" step (second lamination step). The laminated bar is pressed a second time under high pressure to fill and close the bubbles, voids and pockets, in preparation for singulation and firing. The effect of this is to force integration of the materials such that an integrated mixing zone is made. As shown, there are actually two mixing zones. The first mixing zone **222** is between the green alumina insulator **156** and the CRMC **185** paste. A second mixing zone **226** is between the CRMC **185** and the substantially pure platinum **187** pastes. By driving these materials and intermixing them prior to sintering, an intimacy between the alumina and the CRMC and between the CRMC and the pure platinum is achieved, facilitating diffusion and bonding at the interfaces of these materials thereby providing a more robust hermetic seal.

It is understood to those skilled in the art that the novel second pressing step has wide applicability to a number of other teachings. In particular, this process comprising the novel second pressing step is applicable to U.S. Pat. Nos. 8,653,384; 8,938,309; 9,233,253; 9,352,150; 9,511,220; 9,889,306; 9,993,650 and 10,272,253, U.S. Patents, the contents of which are fully incorporated herein by these references. Referring now to U.S. Pat. No. 9,889,306 disclosing co-sintered vias having conductive inserts, it is

appreciated that the novel second pressing step of FIG. **86** may alternatively be accomplished prior to counter-boring or adding a metal insert.

Although several embodiments of the invention have been described in detail for purposes of illustration, various modifications of each may be made without departing from the spirit and scope of the invention. Accordingly, the invention is not to be limited, except as by the appended claims.

What is claimed is:

1. A filtered feedthrough for an active implantable medical device (AIMD), the filtered feedthrough comprising:

a) a hermetic feedthrough, comprising:

  i) an electrically conductive ferrule comprising a ferrule opening;

  ii) an insulator residing in the ferrule opening where a first hermetic seal hermetically seals the insulator to the ferrule, wherein at least one insulator passageway extends through the insulator to an insulator body fluid side surface opposite an insulator device side surface, and wherein, when the ferrule hermetically sealed to the insulator is attached to an opening in an AIMD housing, the insulator body fluid side surface and the insulator device side surface reside outside and inside the AIMD, respectively; and

  iii) a platinum-containing active conductive pathway hermetically sealed to the insulator in the at least one insulator passageway and extending from an active pathway body fluid side to an active pathway device side, the active conductive pathway being in a non-conductive relationship with the ferrule and being characterized as having been a platinum-containing paste filled into the at least one insulator passageway and then co-sintered with the insulator when the insulator is in a green-state; and

b) at least one flat-through filter capacitor disposed on or adjacent to the insulator device side surface of the hermetic feedthrough, the at least one flat-through filter capacitor comprising:

  i) a dielectric substrate supporting at least one active electrode plate interleaved between and in a capacitive relationship with at least two ground electrode plates, wherein the active electrode plate has active electrode plate first and second ends; and

  ii) a first active electrode metallization electrically connected to the at least one active electrode plate first end, a second active electrode metallization electrically connected to the active electrode plate second end, and a ground electrode metallization electrically connected to the at least two ground electrode plates; and

c) a first active electrical connection electrically connecting the active conductive pathway device side to the first active electrode metallization electrically connected to the at least one active electrode plate first end;

d) a second active electrical connection which is connectable from the second active electrode metallization electrically connected to the active electrode plate second end of the at least one flat-through filter capacitor to AIMD circuits housed inside an AIMD housing; and

e) a ground electrical connection electrically connecting the ground electrode metallization to the ferrule.

2. The filtered feedthrough of claim **1**, wherein the first hermetic seal comprises a first gold braze.

3. The filtered feedthrough of claim **1**, wherein the dielectric substrate has a dielectric constant k that is greater than 0 but less than 1000.

4. The filtered feedthrough of claim **1**, wherein the at least one flat-through filter capacitor is located as the first filter capacitor electrically connected to the platinum-containing active conductive pathway at or adjacent to the insulator device side surface of the hermetic feedthrough.

5. The filtered feedthrough of claim **1**, wherein the platinum-containing active conductive pathway of the hermetic feedthrough comprises a co-sintered ceramic reinforced metal composite material or a co-sintered substantially pure platinum material that is hermetically sealed to the insulator in the at least one insulator passageway.

6. The filtered feedthrough of claim **1**, wherein the at least one flat-through filter capacitor is disposed on a circuit board, and wherein at least one circuit board ground plate is disposed on or inside the circuit board, wherein the ground electrical connection comprises a first ground electrical connection electrically connecting the ground electrode metallization of the at least one flat-through filter capacitor to the at least one circuit board ground plate and a second ground electrical connection electrically connecting the at least one circuit board ground plate to the ferrule.

7. The filtered feedthrough of claim **1**, wherein the at least one flat-through filter capacitor is disposed at least partially over the insulator in a tombstone mounted position with the at least one active electrode plate and the at least two ground electrode plates disposed in a perpendicular orientation with respect to the insulator device side surface of the hermetic feedthrough.

8. The filtered feedthrough of claim **2**, wherein the ground electrical connection electrically connects the ground electrode metallization of the at least one flat-through filter capacitor to the first gold braze hermetically sealing the insulator to the ferrule.

9. The filtered feedthrough of claim **6**, wherein the ground electrical connection electrically connecting the at least one circuit board ground plate to the ferrule comprises an oxide-resistant material, the oxide-resistant material being selected from the group of:

a) the first hermetic seal hermetically sealing the insulator to the ferrule;

b) at least one oxide-resistant ground pin that is connected to the ferrule by a third second gold braze or a laser weld;

c) an oxide-resistant area supported by the ferrule, the oxide-resistant area being selected from the group of a gold pocket-pad, a gold pad, an oxide-resistant metal addition, a thermal-setting electrically conductive adhesive (ECA) stripe, and combinations thereof;

d) a ferrule peninsula; and

e) a ferrule-bridge.

10. The filtered feedthrough of claim **9**, wherein the oxide-resistant material is selected from the group of platinum, gold, tungsten, iridium, palladium, niobium, tantalum, ruthenium, rhodium, silver, osmium, and alloys and combinations thereof.

11. The filtered feedthrough of claim **9**, wherein the at least one oxide-resistant ground pin is of a material selected from the group of platinum-rhodium, platinum-iridium, platinum-palladium, platinum-gold and naturally occurring alloys such as platiniridium (platinum-iridium), iridiosmium and osmiridium (iridium-osmium).

12. The filtered feedthrough of claim **1**, wherein an insulating washer is disposed between the at least one flat-through filter capacitor and the hermetic feedthrough.

13. A filtered feedthrough for an active implantable medical device (AIMD), the filtered feedthrough comprising:

a) a hermetic feedthrough, comprising:

i) an electrically conductive ferrule comprising a ferrule opening;

ii) an insulator residing in the ferrule opening where a first gold braze hermetically seals the insulator to the ferrule, wherein at least one insulator passageway extends through the insulator to an insulator body fluid side surface opposite an insulator device side surface, and wherein, when the ferrule hermetically sealed to the insulator is attached to an opening in an AIMD housing, the insulator body fluid side surface and the insulator device side surface reside outside and inside the AIMD, respectively; and

iii) a platinum-containing active conductive pathway hermetically sealed to the insulator in the at least one insulator passageway and extending from an active pathway body fluid side to an active pathway device side, the platinum-containing active conductive pathway being in a non-conductive relationship with the ferrule and being characterized as having been a platinum-containing paste filled into the at least one insulator passageway and then co-sintered with the insulator when the insulator is in a green-state; and

b) at least one flat-through filter capacitor disposed on or adjacent to the insulator device side surface of the hermetic feedthrough, the at least one flat-through filter capacitor comprising:

i) a dielectric substrate supporting at least one active electrode plate interleaved between and in a capacitive relationship with at least two ground electrode plates, wherein the active electrode plate has active electrode plate first and second ends; and

ii) a first active electrode metallization electrically connected to the at least one active electrode plate first end, a second active electrode metallization electrically connected to the active electrode plate second end, and a ground electrode metallization electrically connected to the at least two ground electrode plates; and

c) a circuit board comprising at least one ground electrode plate disposed on or inside the circuit board, wherein the at least one flat-through filter capacitor is disposed on the circuit board;

d) a first active electrical connection electrically connecting the first platinum-containing active conductive pathway device side to the first active electrode metallization electrically connected to the active electrode plate first end;

e) a second active electrical connection which is connectable from the second active electrode metallization electrically connected to the active electrode plate second end of the at least one flat-through filter capacitor to AIMD circuits housed inside an AIMD housing;

f) a first ground electrical connection electrically connecting the ground electrode metallization of the at least one flat-through filter capacitor to the at least one circuit board ground plate; and

g) a second ground electrical connection electrically connecting the at least one circuit board ground plate to the ferrule.

14. The filtered feedthrough of claim **13**, wherein the platinum-containing active conductive pathway of the hermetic feedthrough comprises a pure platinum paste that is filled into the at least one insulator passageway and then characterized as having been co-sintered with the insulator

when the insulator is in a green-state to thereby hermetically seal the pure platinum material conductive pathway to the insulator in the at least one insulator passageway.

15. The filtered feedthrough of claim **13**, wherein the platinum-containing active conductive pathway of the hermetic feedthrough comprises a ceramic reinforced platinum composite paste that is filled into the at least one insulator passageway and then characterized as having been co-sintered with the insulator when the insulator is in a green-state to thereby hermetically seal the ceramic reinforced platinum composite material conductive pathway to the insulator in the at least one insulator passageway.

16. The filtered feedthrough of claim **13**, wherein an insulating washer is disposed between the at least one flat-through filter capacitor and the hermetic feedthrough.

17. The filtered feedthrough of claim **13**, wherein the dielectric substrate of the at least one flat-through filter capacitor has a dielectric constant k that is greater than 0 but less than 1000.

18. The filtered feedthrough of claim **13**, wherein the at least one flat-through filter capacitor is located as the first filter capacitor electrically connected to the platinum-containing active conductive pathway at or adjacent to the insulator device side surface of the hermetic feedthrough.

19. The filtered feedthrough of claim **13**, wherein the second ground electrical connection electrically connecting the at least one circuit board ground plate to the ferrule comprises an oxide-resistant material, the oxide-resistant material being selected from the group of:

a) the first hermetic seal hermetically sealing the insulator to the ferrule;

b) at least one oxide-resistant ground pin connected to the ferrule by a second gold braze or a laser weld;

c) an oxide-resistant area supported by the ferrule, the oxide-resistant material being selected from the group of a gold pocket-pad, a gold pad, an oxide-resistant metal addition, a thermal-setting electrically conductive adhesive (ECA) stripe, and combinations thereof;

d) a ferrule peninsula; and

e) a ferrule-bridge.

20. The filtered feedthrough of claim **13**, wherein the second ground electrical connection electrically connects the at least one circuit board ground plate to the first gold braze hermetically sealing the insulator to the ferrule.

21. A filtered feedthrough for an active implantable medical device (AIMD), the filtered feedthrough comprising:

a) a hermetic feedthrough, comprising:

i) an electrically conductive ferrule comprising a ferrule opening;

ii) an insulator residing in the ferrule opening where a first hermetic seal hermetically seals the insulator to the ferrule, wherein at least one insulator passageway extends through the insulator to an insulator body fluid side surface opposite an insulator device side surface, and wherein, when the ferrule hermetically sealed to the insulator is attached to an opening in an AIMD housing, the insulator body fluid side surface and the insulator device side surface reside outside and inside the AIMD, respectively; and

iii) a active conductive pathway comprising a pure platinum material or a ceramic reinforced platinum composite material hermetically sealed to the insulator in the at least one insulator passageway, the active conductive pathway extending from an active pathway body fluid side to an active pathway device side, wherein the active conductive pathway is characterized as having been a platinum-containing paste

filled into the at least one insulator passageway and then co-sintered with the insulator when the insulator is in a green-state; and

b) at least one flat-through filter capacitor comprising:

i) a dielectric substrate supporting at least one active 5 electrode plate interleaved between and in a capacitive relationship with at least two ground electrode plates, wherein the active electrode plate has active electrode plate first and second ends, and wherein the dielectric substrate has a dielectric constant k that is 10 greater than 0 but less than 1,000,

ii) a first active electrode metallization electrically connected to the at least one active electrode plate first end, a second active electrical connection electrically connected to the active electrode plate sec- 15 ond end, and a ground electrode metallization electrically connected to the at least two ground electrode plates of the flat-through filter capacitor, and

iii) wherein the at least one flat-through filter capacitor 20 is disposed at least partially over the insulator in a tombstone mounted position with the at least one active electrode plate and the at least two ground

electrode plates disposed in a perpendicular orientation with respect to the insulator device side surface of the hermetic feedthrough, and

iv) wherein the at least one flat-through filter capacitor is located as the first filter capacitor electrically connected to the active conductive pathway at or adjacent to the insulator device side surface of the hermetic feedthrough;

c) a first active electrical connection electrically connecting the platinum-containing active conductive pathway device side of the hermetic feedthrough to the first active electrode metallization electrically connected to the active electrode plate first end;

d) a second active electrical connection which is connectable from the second active electrode metallization electrically connected to the active electrode plate second end of the at least one flat-through filter capacitor to AIMD circuits housed inside an AIMD housing; and

e) a ground electrical connection electrically connecting the ground electrode metallization to the ferrule.

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